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FEATURES

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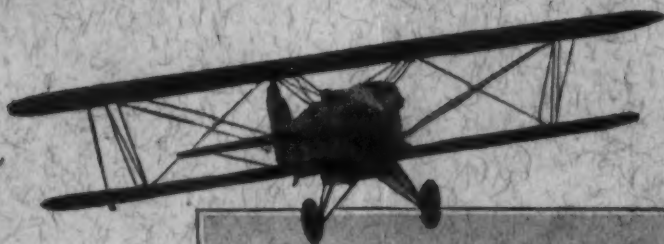
Vol. XIV   August, 1928   No. 2

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EFFECT OF HEAT TREATMENT ON THE PROPERTIES OF CHROMIUM-MOLYBDENUM SHEET STEEL

BY F. T. SISCO AND D. M. WARNER

Abstract

This paper summarizes test results on chromium-molybdenum sheet of a composition suitable for use in aircraft construction. The effects of heat treatment on the physical properties and structure are shown for sheet of several gages. Results indicate that for the best combination of strength and ductility as measured by the ultimate strength, yield point, hardness, elongation, and bend test, the sheet should be normalized, hardened by quenching in water from 1600 degrees Fahr. and tempered between 1000 and 1200 degrees Fahr. It is shown that the elongation of this steel after heat treatment decreases materially as the gage becomes thinner. This fact should be considered in preparing specifications for steel of this composition purchased in the form of sheet. It is also shown by this investigation that for good commercial sheet rolled according to best practice test pieces cut lengthwise or crosswise of the sheet should have the same properties.

CHROMIUM-molybdenum steel, due to its high strength properties, ease of heat treatment and facility of welding and brazing, is finding steadily increasing use in the aircraft and automotive fields. For aircraft it is used in the form of thin-walled tubing for the construction of the fuselage; in the form of sheet

it is used for wing and tail fittings and other structural parts. Wing and tail fittings are exceedingly vital, hence great care must be taken in selecting material for their fabrication.

The work summarized in this investigation was done to aid in the preparation of specifications for the guidance of manufacturers and users of this steel. The chemical composition of this particular grade of chromium-molybdenum steel is required to fall within the following limits:

	Per Cent
Carbon	0.25-0.35
Manganese	0.40-0.60
Phosphorus (maximum)	0.040
Sulphur (maximum)	0.045
Chromium	0.80-1.10
Molybdenum	0.15-0.25

The results embodied in this report show the effects of various heat treatments on the properties and structure of this steel. While the investigation was by no means complete nor exhaustive, sufficient tests were made to indicate strength trends of this material as received from the steel mill and after various heat treatments. From the results obtained it is possible to fix minimum strength requirements for this grade of steel.

METHOD OF TEST

The specimens used in this investigation were cut from a lot of commercial chromium-molybdenum sheet of the following sizes: ¼, ³⁄₁₆, ⅛, 0.094, 0.078, 0.063, 0.050, and 0.0375 inch. The lot was received from one source of supply and was presumably all of the same heat of steel. Approximately 300 standard test specimens were cut, longitudinally and transversely to the longitudinal axis, from representative sheets of each gage.

Specimens were approximately 12 inches long and one inch wide. The heavier gage specimens were finished machined to ¾ inch wide and the lighter gage specimens to ½ inch wide. All were of sufficient length between shoulders to permit measurements for elongation to be made over a 2-inch and a 4-inch gage length. The exact size of the finished specimens is given in the tables. Specimens of the following gages were heat treated: ¼,

⅛, 0.063, and 0.0375 inch. The heat treatment accorded to these test pieces was as follows:

Normalizing: Heat to 1700 degrees Fahr.
              Hold one-half hour.
              Cool in still air.
Hardening: Heat to 1600 degrees Fahr.
              Hold one-half hour.
              Quench in water.
Tempering: Heat to desired temperature.
              Hold one-half hour.
              Cool in still air.

The tempering temperatures were 600, 800, 1000, and 1200 degrees Fahr.

Metallographic specimens were cut from the end of longitudinal and transverse test pieces, representative of the structural condition resulting from the various treatments.

Test specimens were tested in tension according to standard methods. The yield point was taken from the stress-strain curve at that point where the deflection was 0.01 inch in two inches, or 0.005 inch per inch. This in every case is above the actual proportional limit. Rockwell hardness tests (C-scale, diamond point), and Brinell hardness tests (3000 kilograms) were made on the heavier gages only.

Bend tests were made over a mandrel equivalent to one, two or four times the thickness of the specimen tested. The thickness of the mandrel depended upon the heat treatment and is given in the tables.

At the time this investigation was in progress at Wright Field, work on a steel of similar composition was in progress at the metallurgical laboratory of the Central Alloy Steel Corp., Canton and Massillon, Ohio. Their work was to determine the effect on the physical properties of changing the width and thickness of the test specimen. Through the kindness of two members[1] of that organization their results are incorporated in this report.

RESULTS

Careful chemical analysis of sheets of each gage indicated

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[1] E. C. Smith and E. R. Johnson.

Table I

Physical Properties of Chromium-Molybdenum Sheet—As Received

Nominal Size—Inches	¼	¼	3/16	3/16	⅛	⅛	0.094	0.078	0.063	0.050	0.0375
Direction of Specimen	L.	T.	L.	T.	L.	T.	L.	L.	L.	L.	L.
Actual Width, Inches	0.750	0.751	0.750	0.750	0.500	0.500	0.501	0.500	0.502	0.502	0.497
Actual Thickness, Inches	0.255	0.253	0.185	0.185	0.130	0.130	0.096	0.081	0.067	0.050	0.040
Yield Point, Lbs. Per Sq. In.	43,670	45,000	.....	.....	38,670	40,670	.....	.....	56,300	.....	52,000
Ultimate Strength, Lbs. Per Sq. In.	91,700	94,960	87,600	86,900	81,600	87,400	78,150	73,770	74,200	72,500	71,800
Elongation in 2 Inches, Per Cent.	23.7	23.0	25.8	25.5	23.5	23.0	26.5	25.7	26.5	25.7	25.4
Elongation in 4 Inches, Per Cent.	17.8	17.4	19.4	19.1	17.8	17.6	.....	.....	.....	.....	.....
Bend Test, 180°—2T	1-O.K. 2-Fail	1-O.K. 2-Fail	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
Rockwell Hardness—C Scale	7.0	8.5	.....	.....	1.0	5.0	.....	.....	.....	.....	.....
Brinell Hardness—3000 Kg.	173	182	.....	.....	.....	.....	.....	.....	.....	.....	.....
No. Specimens Tested	3	3	3	3	3	3	6	6	6	6	6

ABBREVIATIONS

L.—Longitudinal.
T.—Transverse.
Bend Test, 180° 2T—Bend Test, 180° Over Mandrel Equivalent to Two Times the Thickness of Specimen.

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that the material was extremely uniform in composition. The carbon varied from 0.32 to 0.36 per cent; the manganese from 0.55 to 0.56 per cent; the chromium from 0.86 to 0.91 per cent; and the molybdenum from 0.22 to 0.25 per cent. From the analysis obtained it is evident that there was no excessive decarburization in rolling the thinner gages, as is sometimes encountered in thin sheet of other grades of steel.

The results of this investigation are given in Tables I to VIII. The effect of heat treatment for the four gages above specified is shown in Figs. 1 to 4. Fig. 5 shows the effect of
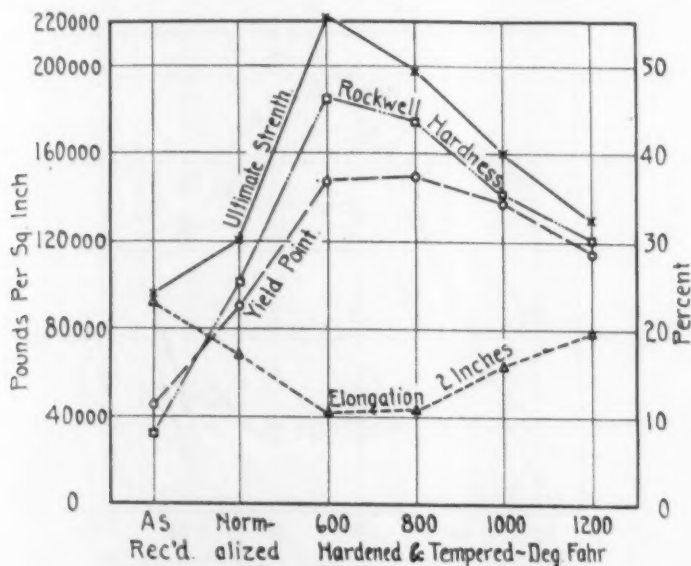
Fig. 1—Curves Showing the Effect of Heat Treatment on ¼-inch Chromium-Molybdenum Sheet.

varying the gage of the test specimen. The structure is shown in Figs. 6 to 18 inclusive. The structures reproduced in this report are from longitudinal specimens only. There was no difference in structure between specimens cut longitudinally from the sheet and those cut transversely. Likewise, there was no appreciable structural difference in specimens hardened and tempered at 600, 800, and 1000 degrees Fahr., and very little difference in structure between those tempered at 600 and 1200 degrees as is evidenced from an examination of the photomicrographs.

DISCUSSION OF RESULTS

It is evident from an examination of Table I that the prop-

erties of chromium-molybdenum sheet as received from the mill
are extremely erratic. This is especially true of the strength
properties. Doubtless this wide variation is due primarily to
different rates of cooling from the finishing temperature after
rolling. From an examination of the structure of three sizes of
the sheet "as received", shown in Figs. 6, 7 and 8 these erratic
properties are to be expected. On this particular lot of sheet,
tentative specifications required that the material pass the bend
test. It will be noted from Table I that all sizes passed satis-
factorily except the ¼-inch gage. In the material "as received"
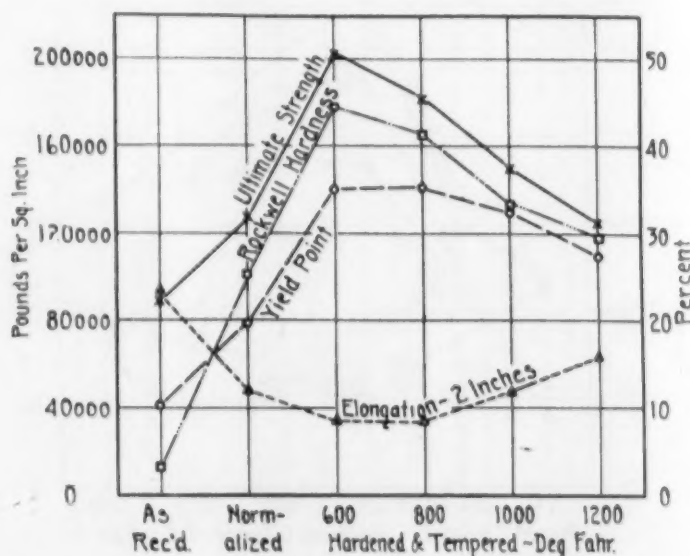
Fig. 2—Curves Showing the Effect of Heat Treatment on
⅛-inch Chromium-Molybdenum Sheet.

there is no appreciable difference in properties of test pieces cut
longitudinally and transversely. As this investigation concerned
the effect of heat treatment only, none of the test specimens were
annealed. An idea of the properties of this steel in the annealed
condition may be obtained from Table VII. The heat treatment
accorded to these specimens by the Central Alloy Steel Corpora-
tion was similar to an anneal. It will be noted by comparing the
results in Table I with those in Table VII, that quenching in
oil from 1550 degrees Fahr. followed by tempering at 1320 or
1375 degrees Fahr. produced strength properties much superior
to that of the material in the "as received" condition. The

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Table II

Physical Properties of Chromium-Molybdenum Sheet—Normalized

Nominal Size—Inches	¼		3/16		⅛		0.094		0.078		0.063		0.050		0.0375	
Direction of Specimen	L.	T.	L.	T.	L.	T.	L.	T.	L.	T.	L.	T.	L.	T.	L.	T.
Actual Width, Inches	0.746	0.746	0.752	0.748	0.499	0.499	0.500	0.497	0.499	0.499	0.500	0.499	0.499	0.493	0.499	0.499
Actual Thickness, Inches	0.251	0.253	0.185	0.184	0.129	0.130	0.094	0.097	0.081	0.083	0.068	0.069	0.051	0.051	0.039	0.039
Yield Point, Lbs. Per Sq. Inch	90,000	88,000	......	......	82,000	76,670	......	......	......	......	79,670	85,000	......	......	73,000	74,000
Ultimate Strength, Lbs. Per Sq. Inch	119,200	119,630	108,230	111,700	119,180	113,500	122,830	125,000	113,360	118,060	117,700	121,170	113,060	113,930	108,200	106,670
Elongation in 2 In., Per Cent	16.6	17.5	18.3	18.3	13.5	14.0	12.5	11.1	13.7	13.3	13.7	12.1	11.5	11.8	10.6	11.0
Elongation in 4 In., Per Cent	10.6	11.8	12.2	12.3	9.0	9.7	8.4	8.8	10.0	9.7	9.8	8.3	8.9	9.9	8.0	8.1
Bend Test, 180°—2T	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	Fail	Fail	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
Rockwell Hardness, "C Scale"	25.0	25.0	......	......	25.0	25.0	......	......	......	......	......	......	......	......	......	......
Brinell Hardness, 3000 kg.	244	259	......	......	244	221	......	......	......	......	......	......	......	......	......	......
Number Specimens Tested	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

elongation especially for the heavier gages is about the same as for the steel in the ''as received'' condition.

The normalizing treatment accorded to all of the specimens was solely to put the material in the proper structural condition so it would respond uniformly to heat treatment. That this steel is appreciably air hardening is evidenced from the results shown in Table II. The tensile properties are fairly uniform at
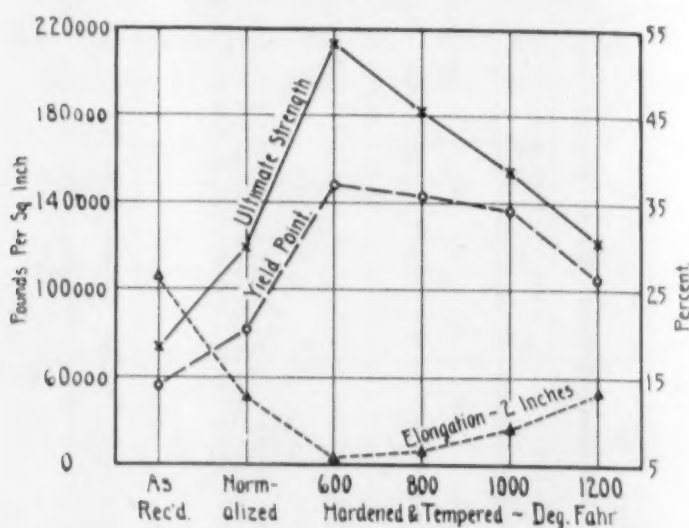
Fig. 3—Curves Showing the Effect of Heat Treatment on 0.063-inch Chromium-Molybdenum Sheet.

110,000 to 120,000 pounds per square inch for the ultimate strength and 80,000 to 90,000 pounds per square inch for the yield point. Only the thinnest gage, the 0.0375 gave low results. In general this size gave low results for each of the various heat treatments. This was undoubtedly due to a small amount of decarburization caused by heat treatment. On several specimens a slight low carbon surface layer could be detected by the microscope. Table II shows plainly the close agreement between the properties of longitudinal test pieces and those taken crosswise of the sheet. The agreement is close for each size. Table II also illustrates the steady decrease in elongation as the gage becomes thinner. This decrease is evidenced on all of the heat treated specimens.

Tables III, IV, V, and VI, show the properties of the steel hardened in water and tempered at the temperatures shown in the table. The only peculiarities on these four tables are the relatively low properties for the 0.0375-inch sheet and the uniform

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Table III

Physical Properties of Chromium-Molybdenum Sheet—Normalized, Hardened and Tempered at 600 Degrees Fahr.

Nominal Size—Inches Direction of Specimen	¾ Long.	¾ Transverse	⅛ Long.	⅛ Transverse	0.063 Long.	0.063 Transverse	0.0375 Long.	0.0375 Transverse
Actual Width, Inches	0.748	0.746	0.494	0.501	0.499	0.501	0.504	0.504
Actual Thickness, Inches	0.250	0.253	0.129	0.129	0.066	0.064	0.039	0.038
Yield Point, Pounds Per Square Inch	146,330	148,330	139,670	139,330	148,670	147,330	146,000	148,000
Ultimate Strength, Pounds Per Square Inch	218,000	223,460	203,630	203,000	213,400	211,600	164,300	170,560
Elongation in 2 Inches, Per Cent	10.5	9.6	8.1	8.0	5.8	5.8	4.5	4.5
Elongation in 4 Inches, Per Cent	7.6	6.0	5.1	4.8	3.4	3.7	2.5	2.5
Bend Test, 180 Degrees—4T	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
Rockwell Hardness, "C Scale"	47.0	46.0	44.5	44.0	.....	.....	.....	.....
Brinell Hardness, 3000 kg.	441	441	423	415	.....	.....	.....	.....
Number Specimens Tested	3	3	3	3	3	3	3	3

Table IV

Physical Properties of Chromium-Molybdenum Sheet—Normalized, Hardened and Tempered at 800 Degrees Fahr.

Nominal Size—Inches Direction of Specimen	¾ Long.	¾ Transverse	⅛ Long.	⅛ Transverse	0.063 Long.	0.063 Transverse	0.0375 Long.	0.0375 Transverse
Actual Width, Inches	0.745	0.741	0.499	0.499	0.501	0.501	0.500	0.500
Actual Thickness, Inches	0.251	0.251	0.129	0.129	0.068	0.067	0.038	0.038
Yield Point, Pounds Per Square Inch	148,030	149,670	139,330	141,670	143,330	138,330	145,330	144,000
Ultimate Strength, Pounds Per Square Inch	194,200	197,700	182,300	180,500	182,150	181,500	176,600	170,100
Elongation in 2 Inches, Per Cent	10.8	10.3	8.3	8.3	6.0	6.8	3.6	5.8
Elongation in 4 Inches, Per Cent	6.7	6.3	5.6	5.6	4.2	3.4	2.4	2.8
Bend Test, 180 Degrees—4T	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
Rockwell Hardness, "C Scale"	43.0	43.5	42.0	41.0	.....	.....	.....	.....
Brinell Hardness, 3000 kg.	406	409	390	370	.....	.....	.....	.....
Number Specimens Tested	3	3	3	3	3	3	3	3

decrease in elongation as the sheet decreases in thickness.

Tables III to VI indicate that this steel hardened and tempered at 600 and 800 degrees Fahr. is too brittle to pass a bend
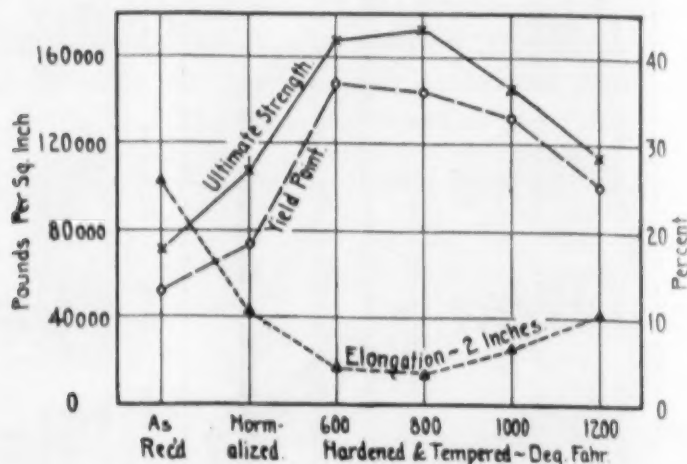
Fig. 4—Curves Showing the Effect of Heat Treatment on 0.0375-inch Chromium-Molybdenum Sheet.
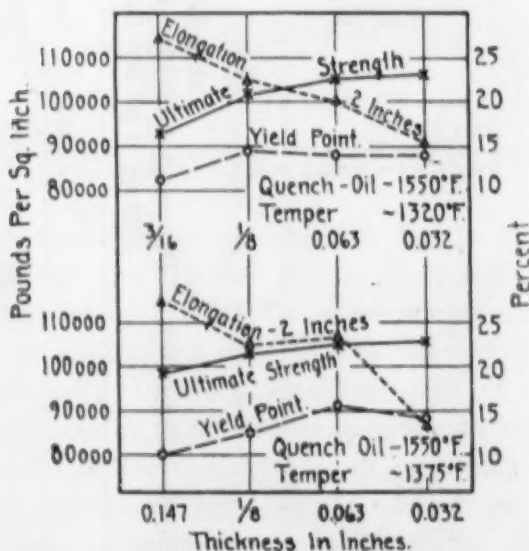
Fig. 5—Curves Showing the Effect of Thickness of Specimen of Chromium-Molybdenum Sheet.

test requirement even though a mandrel equivalent to four times the thickness is permitted. With a tempering temperature of 1000 degrees Fahr. all sizes below ⅛ inch should pass a bend test over two thicknesses, and when tempered at 1200 degrees Fahr.

Table V

Physical Properties of Chromium-Molybdenum Sheet—Normalized, Hardened and Tempered at 1000 Degrees Fahr.

Nominal Size—Inches	¼		⅛		0.063		0.0375	
Direction of Specimen	Long.	Transverse	Long.	Transverse	Long.	Transverse	Long.	Transverse
Actual Width, Inches	0.746	0.746	0.492	0.500	0.495	0.495	0.497	0.500
Actual Thickness, Inches	0.248	0.253	0.130	0.129	0.066	0.066	0.038	0.037
Yield Point, Pounds Per Square Inch	134,670	138,330	127,670	131,670	140,000	135,670	134,670	129,670
Ultimate Strength, Pounds Per Square Inch	157,830	156,680	149,660	150,760	157,100	152,420	148,470	140,630
Elongation in 2 Inches, Per Cent	16.0	15.3	12.0	11.5	9.1	8.8	6.1	7.1
Elongation in 4 Inches, Per Cent	9.4	9.3	8.1	8.0	6.0	5.9	4.5	4.5
Bend Test, 180 Degrees—2T	Fail	Fail	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
Rockwell Hardness, "C Scale"	34	33	32	32	.....	.....	.....	.....
Brinell Hardness, 3000 kg.	347	341	341	346	.....	.....	.....	.....
Number Specimens Tested	3	3	3	3	3	3	3	3

Table VI

Physical Properties of Chromium-Molybdenum Sheet—Normalized, Hardened and Tempered at 1200 Degrees Fahr.

Nominal Size—Inches	¼		⅛		0.063		0.0375	
Direction of Specimen	Long.	Transverse	Long.	Transverse	Long.	Transverse	Long.	Transverse
Actual Width, Inches	0.746	0.746	0.501	0.500	0.498	0.500	0.499	0.500
Actual Thickness, Inches	0.251	0.253	0.127	0.128	0.066	0.065	0.038	0.038
Yield Point, Pounds Per Square Inch	113,670	111,670	110,330	108,330	104,670	106,330	102,000	99,000
Ultimate Strength, Pounds Per Square Inch	128,130	128,100	128,170	121,530	122,430	121,000	116,700	112,000
Elongation in 2 Inches, Per Cent	19.5	19.3	15.6	15.3	13.6	12.6	10.8	10.8
Elongation in 4 Inches, Per Cent	13.0	13.0	10.5	10.3	9.3	8.8	8.1	8.1
Bend Test, 180 Degrees—1T	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
Rockwell Hardness, "C Scale"	31.0	28.5	30.0	29.6	.....	.....	.....	.....
Brinell Hardness, 3000 kg.	286	277	272	260	.....	.....	.....	.....
Number Specimens Tested	3	3	3	3	3	3	3	3

Table VII

Physical Properties of Chromium-Molybdenum Sheet—Effect of Width of Specimen on Properties

Nominal Size—Inches	³⁄₁₆			0.147			0.094			0.0375			
Direction of Specimen	L.	L.	L.	L.	L.	L.	L.	L.	L.	L.	L.	L.	L.
Actual Width, Inches	1.000	0.750	0.500	1.000	0.750	0.500	1.000	0.750	0.500	1.000	0.880	0.760	0.500
Actual Thickness, Inches	0.187	0.188	0.186	0.149	0.149	0.148	0.094	0.093	0.094	0.037	0.036	0.037	0.037
Yield Point, Pounds Per Square Inch	81,620	79,470	80,800	79,250	84,450	82,500	78,210	80,790	79,700	82,550	80,250	80,700	84,400
Ultimate Strength, Lbs. Per Sq. Inch	93,320	93,500	94,200	99,300	109,600	101,250	91,400	93,400	91,540	89,560	87,900	88,200	91,740
Elongation in 2 Inches, Per Cent	27.2	25.6	23.2	27.5	25.8	23.5	21.5	22.0	18.9	29.0	21.9	20.0	17.0
Elongation in 4 Inches, Per Cent	16.9	17.0	16.3	......	......	......	14.5	15.4	14.0	14.6	14.1	13.4	13.0
Number Specimens Tested	4	3	3	2	2	2	5	5	5	4	4	4	4
Heat Treatment	Quenched in oil from 1550° F. Tempered at 1820° F.			Quenched in oil from 1550° F. Tempered at 1375° F.			Quenched in oil from 1550° F. Tempered at 1320° F.			Quenched in oil from 1550° F. Tempered at 1375° F.			

Table VIII

Physical Properties of Chromium-Molybdenum Sheet—Effect of Thickness of Specimen on Properties

Nominal Size—Inches	³⁄₁₆	⅛	¹⁄₁₆	¹⁄₃₂	0.147	⅛	¹⁄₁₆	0.030
Direction of Specimen	Long.	Long.	Long.	Long.	Long.	Long.	Long.	Long.
Actual Width, Inches	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Actual Thickness, Inches	0.187	0.125	0.063	0.032	0.148	0.125	0.063	0.030
Yield Point, Pounds Per Square Inch	81,600	88,830	87,500	87,900	79,250	85,400	91,500	87,500
Ultimate Strength, Pounds Per Square Inch	93,320	102,200	104,600	105,440	99,000	102,900	105,200	105,900
Elongation in 2 Inches, Per Cent	27.0	22.5	20.0	14.9	27.3	27.0	23.3	13.0
Elongation in 4 Inches, Per Cent	16.9	15.2	13.5	10.6	......	17.8	15.0	9.5
Number Specimens Tested	4	4	4	4	2	3	2	3
Heat Treatment	Quenched in Oil from 1550° F. Tempered at 1320° F.				Quenched in Oil from 1550° F. Tempered at 1375° F.			

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all sizes should pass a bend test over a mandrel equivalent to one thickness. Probably the best combination of physical properties, including strength and ductility, will be obtained with a tempering temperature of about 1100 degrees Fahr.

All of the results obtained in this investigation indicate that on chromium-molybdenum sheet rolled according to best commer-

Fig. 6—Photomicrograph of ¼-inch Chromium-Molybdenum Sheet as Received. Magnification × 500.

cial practice there should be no difference in properties on test pieces cut either longitudinally or transversely.

The results recorded in Tables I to VI are summarized for each of the four representative gages in Figs. 1 to 4. In general these graphs are self explanatory. One peculiarity noted on all four gages is the slight difference in properties for a tempering temperature of 600 and 800 degrees Fahr. In general the ultimate strength and hardness are slightly higher for the lower tempering temperature. There is practically no difference in elongation or yield point on any of the four sizes for these two tempering temperatures.

The effect of heat treatment on the structure is shown in Figs. 9 to 18. As normalized (Figs. 9, 10, 11) the structure is a coarse sorbite. As hardened (Figs. 12, 13, 14) it is apparently a fine-grained martensite, or troosto-martensite. There is very little structural difference between the specimens tempered at 600 de-
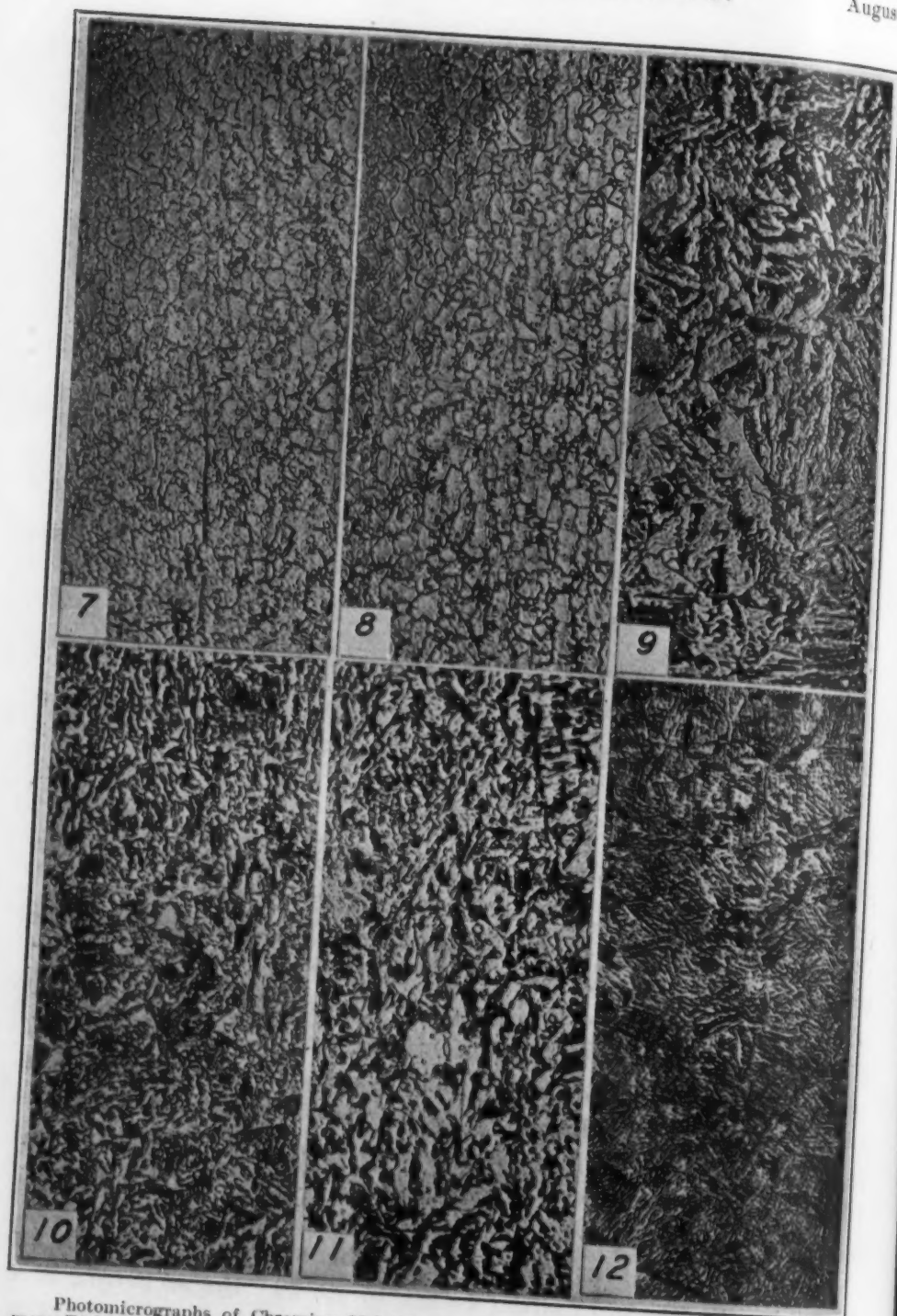
Photomicrographs of Chromium-Molybdenum Sheets of Varying Thickness. All Specimens Etched in Alcoholic Nitric Acid. All Specimens Longitudinal. Mag. × 500. Fig. 7—0.063-inch as Received. Fig. 8—0.0375-inch as Received. Fig. 9—0.25-inch Normalized. Fig. 10—0.063-inch Normalized. Fig. 11—0.0375-inch Normalized. Fig. 12—0.25-inch Hardened, not Tempered.
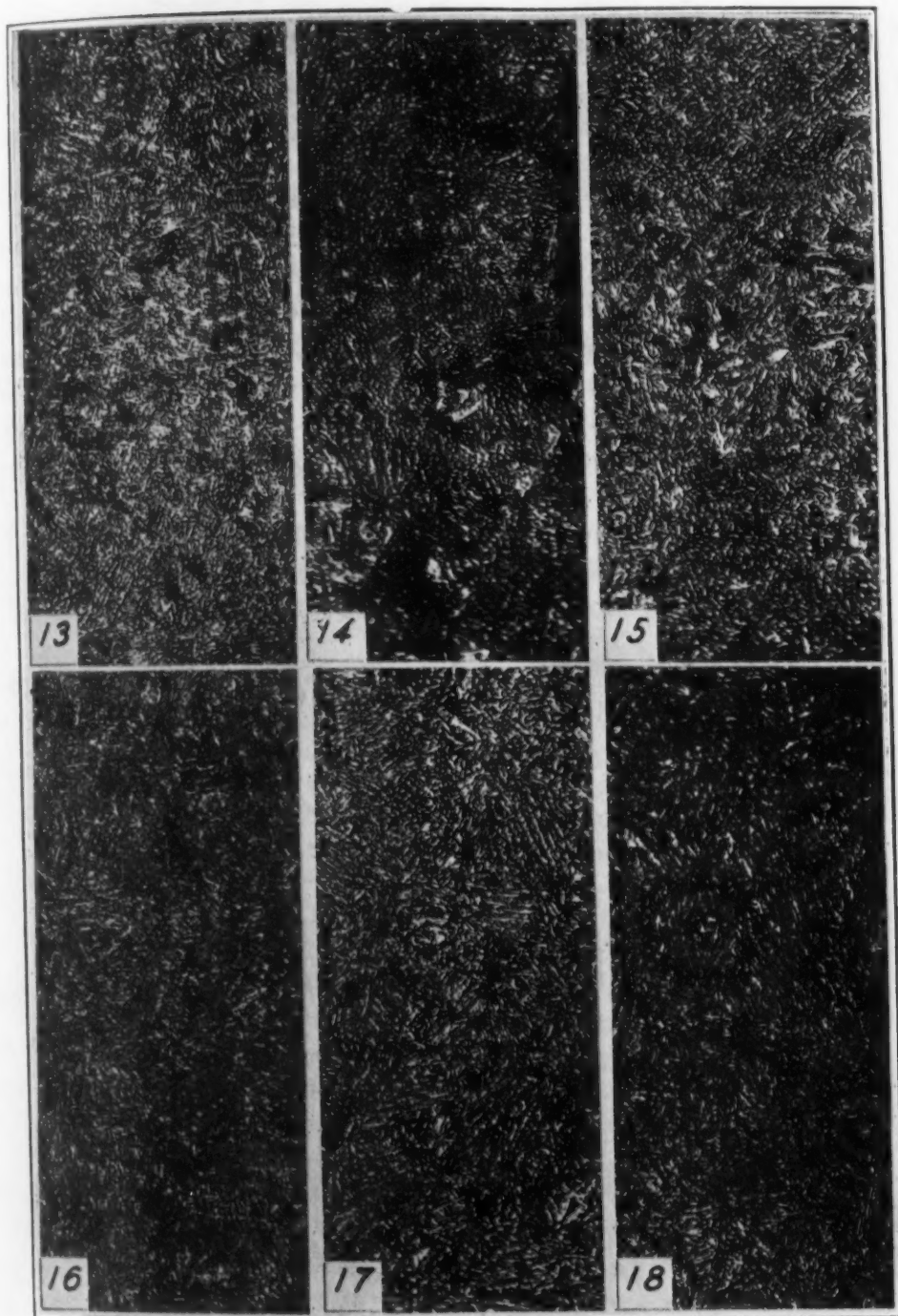
Photomicrographs of Chromium-Molybdenum Sheets of Varying Thickness. All Specimens Etched in Alcoholic Nitric Acid. All Specimens Longitudinal. × 500. Fig. 13—0.063-inch Hardened, not Tempered. Fig. 14—0.0375-inch Hardened, not Tempered. Fig. 15—0.25-inch Hardened, Tempered at 600 degrees Fahr. Fig. 16—0.063-inch Hardened, Tempered at 600 degrees Fahr. Fig. 17—0.25-inch Hardened, Tempered at 1200 degrees Fahr. Fig. 18—0.063-inch Hardened, Tempered at 1200 degrees Fahr.

grees Fahr. (Figs. 15 and 16) and those tempered at 1200 (Figs 17 and 18).

The results obtained by the Central Alloy Steel Corp. on this steel are given in Tables VII and VIII. Table VII shows the effect of reducing the width of the specimen, and Table VIII the effect of reducing the thickness of the specimen.[2]

From Table VII it is evident that reducing the width of the test specimen has no effect on the strength; it does, however, reduce the elongation about 2 per cent. Reducing the thickness of the test specimen does not greatly affect the strength, but it does reduce the elongation markedly. This is clearly shown in Table VIII and in Fig. 5. The slight increase in ultimate strength shown in Table VIII and Fig. 5 is not sufficient to be called characteristic. The marked reduction in elongation of the thinner gages is also clearly evident in the work done at Wright Field and summarized in Tables II to VI. A specification for chromium-molybdenum steel of this composition should take this decrease into account.

Acknowledgment is made to Clifford McMahon and Ture Oberg for their assistance in the work.

[2]The specimens originally taken for this work were the widest shown in Table VII and the thickest shown in Table VIII. The width, or thickness, as the case may be, was reduced, by machining, to that shown in the table.

HEAT TREATMENT OF FORGINGS AND CASTINGS FOR SELECTIVE DIRECTIONAL ADJUSTMENT OF RESIDUAL STRESSES

By W. J. Merten

Abstract

This paper discusses the methods of selective abstraction of heat or selective cooling, by a directed quenching, for the purpose of producing favorable directional internal or residual stresses in forged disks or cast parts of rotating bodies. Ordinary cooling from the periphery toward the center is conducive to conditions detrimental to their application and their subjection to centrifugal stresses.

It describes the directing of the coolant upon the middle of the rotating hollow bored or forged disk by properly placed spraying nozzles or by enclosing the red hot disk in a container with ports at the middle of both sides and immersing same into the coolant and then simultaneously opening the ports and rotating the disks. The change from the ordinarily existing compressive stresses in disks cooled from the periphery to tensional stresses and at the middle to compression is thereby accomplished resulting in a favorable condition of direction of residual stresses in such disks with relation to service stresses under high speed rotation.

Introduction

MAXIMUM exploitation of steel parts without decreasing the factor of safety by introducing internal stresses opposite in sign or direction to the working stresses is in some instances made use of and greater life in service and more satisfactory performance of these parts is obtained, e. g., (1) Cold working or expanding of gun tubes[1] and high pressure vessels hydraulically, (2) In spring manufacture, directional adjustment of internal stresses to aid resistance to torsional service stresses in helical compression

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[1] Dr. Langenberg, Transactions, American Society for Steel Treating, October, 1925.

springs by internal quenching has been strongly advocated by G.
M. Eaton[2]. To the designer the problem of making use of internal
stresses in steel or metallic members of machinery in which the
working stresses are not alternating or are in only one direction has
not even presented itself. To produce residual stresses so as to
aid in reducing the effective working or service stresses by selective
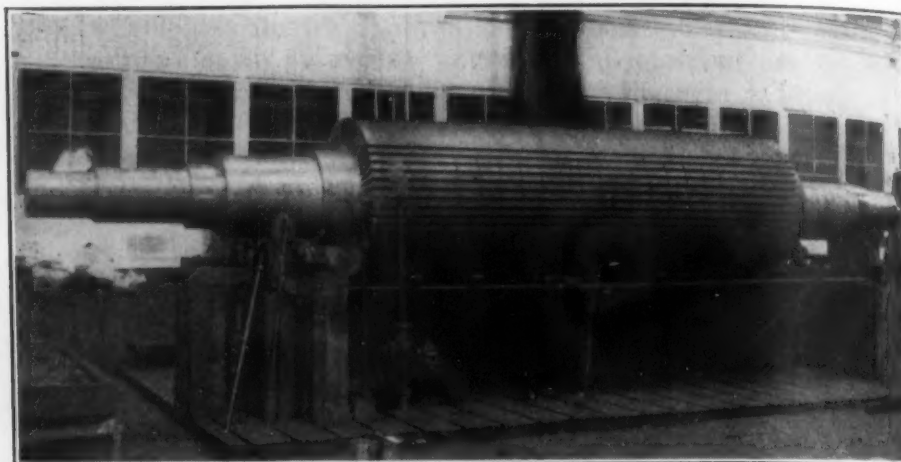
Fig. 1—Assembled and Machined Turborotor.

quenching methods for directional adjustment of the internal
stresses is still an undeveloped practice. The importance how-
ever is marked and any experimenting in this direction is bound to
result in advantageous uses of materials which would ordinarily
be passed up by the design engineer as not being safe in such
service.

INTERNAL STRESSES INTRODUCED BY QUENCHING

In high speed rotating electrical machinery the working stresses
are principally in one direction introducing tensional stresses quite
large in value. When these working stresses are amplified by
residual stresses introduced through the manufacturing processes
the calculated factor of safety will be seriously impaired when
these stresses are in the same direction as the working stresses.

It is usually possible but inadvertently neglected to so quench
or cool steel parts composing these rotating bodies, that the residual
stresses aid in resisting the working stresses, that is they produce

[2]G. M. Eaton, TRANSACTIONS, American Society for Steel Treating, November, 1927.

internal stresses opposite in sign to the working stress, reducing thereby the effective service stress by the amount of the residual stress. This obviously cannot apply to machinery whose members or parts are subjected to alternating stresses. In a study of Fig. 1 a photograph of an assembled and machined turborotor, it is at
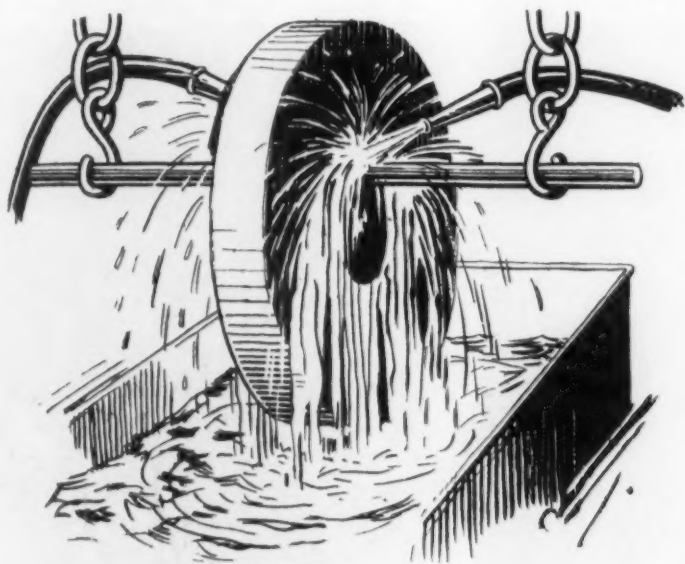
Fig. 2—Drawing Illustrating the Method of Spray Quenching a Disk.

once evident that whatever the direction or magnitude of the residual stresses in the peripheral portion of the rotor disks may be before machining, they are relieved practically entirely after machining is completed and aside from possible binding of the cutting tool little if any difficulties will be encountered from this source. Not so however in the mid portion of the rotor disks.

The stresses are high due to the design, and after ordinary quenching or cooling methods, the internal stresses are tensional or they are in the same direction as the working stresses, consequently, adding thereto and increasing the total stresses. To reverse the sign of these residual stresses or change them to compression stresses obviously would be of considerable aid to retain or even increase the factor of safety and allow of greater working stresses. In hollow-forged or bored disks, this can be accomplished by cooling from the middle to the outside by directing water spraying nozzles against the surfaces of the disk at the center of the vertically rotating disk supported on a mandrel through the

center hole, suspended from a crane over a quenching tank. See sketch Fig. 2, also Fig. 3, photomicrograph of structure of quenched disk.

The compressive stresses produced may be anywhere from 5000 to 15,000 pounds per square inch, or more. Subsequent tempering
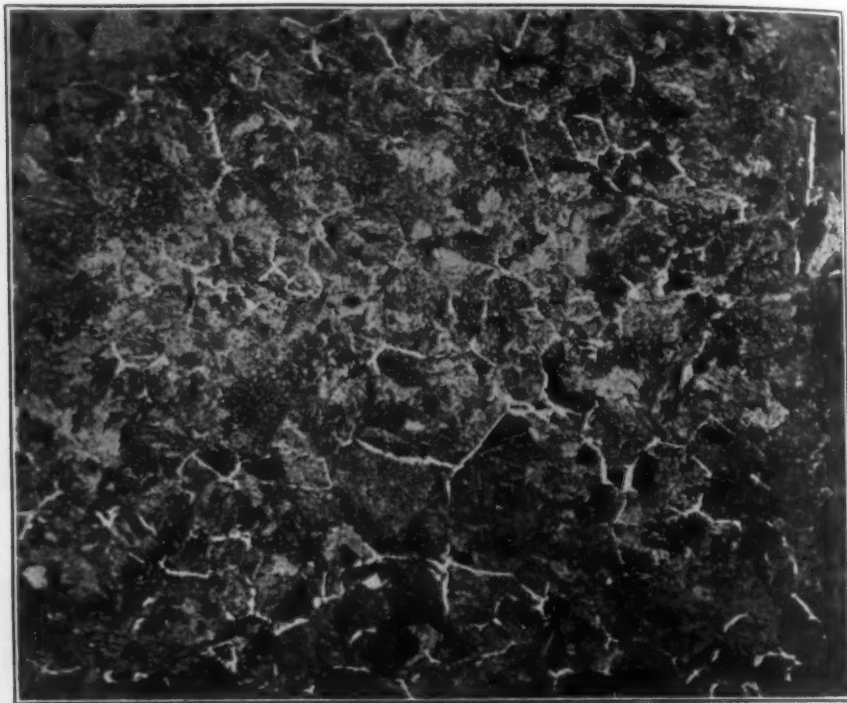
Fig. 3—Photomicrograph Showing Sorbitic Structure of Quenched Disk. × 100.

relieves these stresses an appreciable amount. However, they are seldom entirely removed, as evidenced by movement of the material when slotting or grooving. The remaining internal stresses will gradually relieve themselves during service but any resulting adjustment will be in a favorable direction.

Obviously there are a large number of forged shapes as well as castings where this selective cooling for adjustment of direction of internal stresses is subconsciously made use of. The recognition of the principle and its intelligent and practical application in thermal treatments of steel and metal parts offers so many advantages and may in a great number of cases mean success or failure of proper service performance of such parts that it seems worthwhile to give serious thought to it whenever thermal treat-

ments of forgings and castings are considered and take advantage
of the increased factor of safety by allowing greater working
stresses.

In concluding it should be stated that the measurements and
evaluation of stresses, which were made by our research laboratory
have been purposely omitted since it is the principle of employing
internal stresses for useful work by directing their formation and
not their magnitude that is of primary importance.

REFERENCES

1. "Stresses in Quenched and Tempered Steel." By S. L. Hoyt—TRANSAC-
   TIONS, American Society for Steel Treating, Vol. XI, 1927, Page 509.
2. "Internal Stresses in Cold Wrought Metals and Some Troubles Caused
   Thereby." By E. Heyn—Lecture, Institute of Metals, May 1914.
3. "Effect of Cold Working on the Strength of Hollow Cylinders." By
   F. C. Langenberg—TRANSACTIONS, American Society for Steel Treating,
   Vol. VIII, 1925, Page 447.
4. "Design from the Heat Treating Standpoint." By G. M. Eaton—TRANS-
   ACTIONS, American Society for Steel Treating, Vol. XII, 1927, page 794.

DISCUSSION

Written Discussion: By A. B. Kinzel, Union Carbide and Carbon Re-
search Laboratories, Long Island City, N. Y.

Mr. Merten has pointed out in a very clear manner how residual stresses
may be made to work favorably. This idea is one that has been long used
by heat treaters, particularly in the saw industry. In the case of circular
saws, the thickness of the blade at the center is equal to or less than that
at the rim, whereas the stresses produced by the rotation are very much
greater at the center. This is well recognized in turbine design as evidenced
by the parabolic cross-section of the rotor with maximum thickness at the
hub. In order to have the disk run in a plane, it is necessary to so adjust
the internal stress in the blade that the stresses in operation at the center
and at the rim are approximately equal. This is done by so quenching the
saw blade that the center is in compression, and by subsequently hammer-
ing the blade or "tensioning" as the saw maker calls it, so that the magni-
tude of these compressive stresses is increased. Accurate calculations have
been made showing the exact extent of these stresses, and blades have been
cut up and measured to check the theory. It seems that this case is exactly
parallel to Mr. Merten's rotor plates and should be of interest.

Written Discussion: By E. E. Thum, The Iron Age, New York City.

I would like to ask Mr. Merten a question regarding the make-up of
the large rotors which are illustrated in Fig. 1, page 194. These have an
outer appearance of a huge forging, yet this paper has to do with the heat
treatment of round disks. How were these disks assembled into the form
of a large rotor?

Author's closure: Mr. Kinzel's discussion referring to the use of directed quenching of circular saws to produce compression in the center is of course another case which should be mentioned in parallel with the turbo disk quenching for adjustment of internal stresses, although it is an entirely different matter to produce results in a thin disk saw and then do this in a massive forging weighing several tons, although the principle is the same. Mechanical adjustment or tensioning by peening is of course a well-known way to introduce favorable conditions in large high speed rotating bodies. However, the directed quenching methods are practically unknown in large forging work.

In answer to Mr. Thum's question, I should have stated that Fig. 1 shows an assembled rotor built up of 22 disk forgings 8 inches thick and 56 inches in diameter, weighing approximately 5000 pounds each and fastened to the heavy flanged half ends by four long 5-inch diameter bolts.

AN ASSUMPTION AS TO THE CAUSE OF THE ALLOTROPIC CHANGES OF IRON

By Donovan Jones

Abstract

This paper attempts to show that the changes occurring in iron when heated and cooled are due to changes in the iron atom and suggests the probable changes with their cause and mechanism. It is recognized that there is no real proof given and that the explanations are far from complete, but it is hoped that it will, in some measure, serve to throw light on these changes.

It is postulated that the crystal structure and properties of other metals may be similarly connected with their atom structure.

IT IS well known that pure iron at room temperature has a body-centered cubic lattice structure and that above A_2 the lattice structure is also body-centered cubic, but above A_3 the iron exists with a face-centered cubic lattice structure, while above the A_4 point the iron reverts to the body-centered cubic lattice.

It seems reasonable to suppose that to form a lattice of definite, fixed structure, the atoms comprising that structure should exert definite directional forces of attraction and repulsion. It also seems reasonable to suppose that the atom, to exert definite directional forces of attraction and repulsion, must of itself possess a definite and fixed structure, that is, the electrons of the atom must be arranged in definite and fixed positions with regard to the nucleus and to themselves.

The atom as described by Langmuir[1] is taken, with perhaps some modifications, as the basis of the present theory.

In Fig. 1 is the iron atom, described by Langmuir as follows: "Close to the nucleus are two electrons. The 24 remaining electrons arrange themselves in 3 layers at the corners of 3 concentric cubes (slightly flattened) whose diagonals coincide."

Hull[2] finds that the intensities of the lines in the X-ray spectra of crystals are best accounted for on the theory that the electrons occupy definite positions in the crystal lattice.—''that 8 of the 26 electrons in each atom are arranged along the cube diagonals at a distance from the center equal to one-fourth of the distance to the nearest atom.—If all the electrons are displaced from the center of
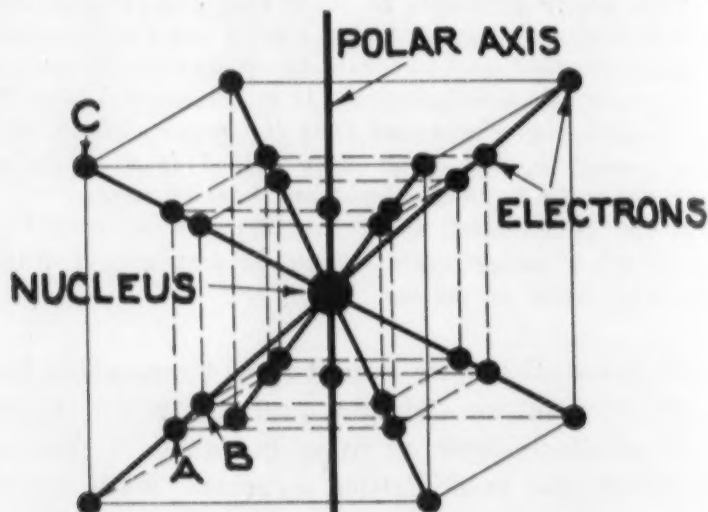
Fig. 1—Diagram of the Alpha Iron Atom.

the atom along the cube diagonals in groups of 2, 8, 8, 8 at distances $\frac{1}{32}$, $\frac{1}{16}$, $\frac{1}{8}$, and $\frac{1}{4}$ respectively, of the distance to the nearest atom, all the observed facts are accounted for within the limit of experimental error.'' Langmuir says of this, ''The structure thus proposed by Hull is identical with that to which we are led by our present theory, except that we should expect the radii of the electron shells to be more uniform than the values given by Hull.''

Hull's results indicate that there are 6 electrons in a line between the centers (nuclei) of each pair of adjacent iron atoms. This would appear as in Fig. 2. Here it is seen that the attractive and repulsive forces of the atom are being exerted in the direction of a line passing from the nucleus through the electrons. As may be seen, this arrangement of the atom, if the attractive and repulsive forces are being exerted as stated above, will naturally form the body-centered cubic lattice.

It is proposed that this is the structure of the iron atom in alpha iron.

[2]Hull, *Physical Review*, Vol. 9, p. 84. 1917.

The Alpha to Beta Transformation—A$_2$.

Temperature of Transformation 1415 degrees Fahr. (768 degrees Cent.).

Langmuir says, "Postulate 5.—It is assumed that electrons contained in the same cell (A and B Fig. 1) are nearly without effect on each other. But the electrons in the outside layer (C Fig. 1) tend to line themselves up (in a radial direction) with those of the underlying shell because of a magnetic field probably always to be
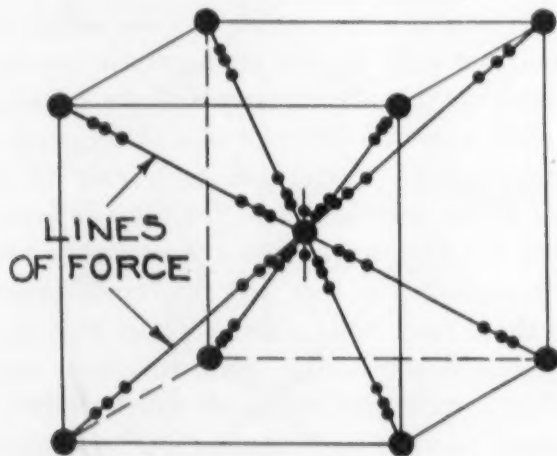
Fig. 2—Diagram Showing Manner in which the Atom is Positioned in Space Lattice of Alpha Iron.

associated with electrons bound in atoms. (Parsons' magneton theory). This attraction may be more or less counteracted by the electrostatic repulsion between the outside electrons and those in the underlying shell. The electrons in the outside layer also repel each other and thus tend to distribute themselves among the available cells so as to be as far apart as possible. The actual positions of equilibrium depend on a balance between these three sets of forces together with the attractive force exerted by the nucleus."

"Postulate 6.—When the number of electrons in the outside layer is small, the magnetic attraction exerted by the electrons of the inner shells tends to predominate over the electrostatic repulsion, but when the atomic number and the number of electrons in the outside layer increase, the electrostatic forces gradually become the controlling factor. As a result, when there are few electrons in the outer layer these arrange themselves in the cells over those of the underlying shell, but where the outside layer begins to ap-

proach its full quota of electrons the cells over the underlying electrons tend to remain empty....

....Although the iron atom possesses about as high a degree of symmetry as that of argon it differs radically from the latter in that the outer shell is not saturated, only 4 of the 9 cells in each hemisphere being occupied by electrons (Postulate 3). Furthermore the number of electrons in the outside shell is beginning to be so great that the electrostatic repulsion (Postulate 6) tends to decrease the stability of this arrangement....

....The ferromagnetic properties of iron, cobalt, and nickel undoubtedly depend not only on the arrangement of the electrons in the atom, but also on the arrangement of the atoms with respect to each other. Hull's results indicate that there are 6 electrons in a line between the centers (nuclei) of each pair of adjacent iron atoms. The two which correspond to the outside layer are held by weak constraints, but the inner ones are probably held at least as firmly as those in argon. The fact that the ferromagnetic properties disappear when these are heated above certain critical temperatures even without change in crystalline form indicates that the outside electrons are subject to thermal agitation which destroys the regular structure necessary for the development of ferromagnetism.''

It is therefore suggested by the present writer that Fig. 3 represents the atom of beta iron. Here the atom is the same as in alpha iron with the exception that the electrostatic repulsion of the 8 outside electrons has overcome the magnetic field of the underlying electrons sufficiently to have moved them about the polar axis 45 degrees.

It is supposed that this change in the atom accounts for the changes observed at Ac₂ as follows:

1—The progressive loss of ferromagnetism with rising temperature is explained on the ground that the increased energy imparted to the 8 outside electrons increases their amplitude of vibration disturbing the magnetic field and on reaching the critical temperature of 1415 degrees Fahr. (768 degrees Cent.) the electrons suddenly break away from the underlying electrons and assume their new positions with consequent loss of ferromagnetism as explained above by Langmuir.

2—It is conceivable that while the change in the atom is not sufficient to cause a change in the space lattice, there will be some

slight difference in the lattice sufficient to account for the slight contraction found by some investigators at Ac_2.

3—The increase in the heat content is the energy absorbed by the 8 outside electrons on moving to their new positions.
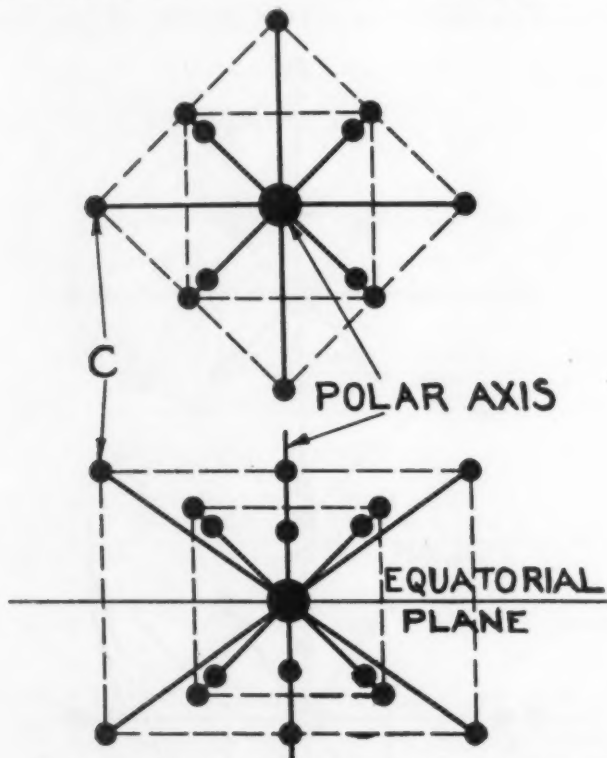
Fig. 3—Diagram of Proposed Beta Atom. This is the Same as Fig. 1 Except that the 8 Outside Electrons C have Moved 45 Degrees with Respect to the Polar Axis.

4—The increase in tensile strength is due to the new lines of force set up by the atom in the direction of the new positions of the outside electrons, tending to eliminate the planes of easy slip.

5—Due to the exceedingly small mass of the electrons there is practically no inertia to overcome in moving to their new positions, with consequent absence of hysteresis with Ar_2.

THE BETA TO GAMMA TRANSFORMATION—A_3.

Equilibrium Temperature of Transformation 1652 degrees Fahr. (900 degrees Cent.).

It is suggested that further heating so increases the electrostatic repulsion of the electrons for each other that they now assume the positions as shown in Fig. 4. As may be seen this

arrangement has a high degree of symmetry with the electrons in each cell as far from those in the other cells as possible but still keeping their same relative distance from the nucleus. This arrangement of the atom is quite different from that of the alpha or beta atom. The electrons are no longer at the corners of con-
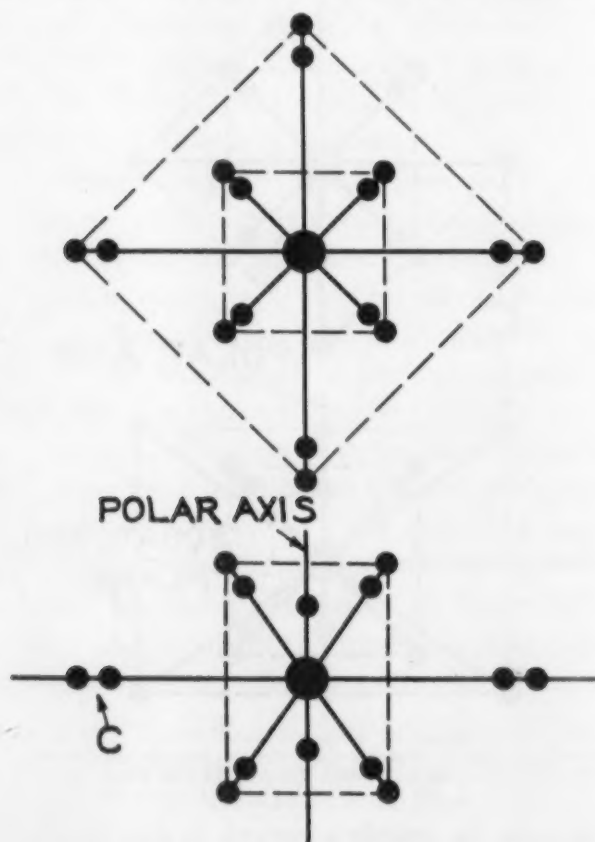
POLAR AXIS

Fig. 4—Diagram of Proposed Gamma Atom. Here the 8 Outside Electrons C are in the Equatorial Plane and Since they can Move no Further, Force the Inner Electrons Toward the Polar Axis.

centric cubes, but still form squares with respect to the polar axis. If the atoms exert forces of attraction and repulsion in the direction of a line passing from the nucleus through the electrons, and the distance from atom to atom remains the same, it will be evident that the space lattice must change to the form shown in Fig. 5, the face-centered cubic lattice.

If the atomic distance remains the same as in the body-centered lattice the side of the new lattice should be proportional to that of the old lattice, i. e., the side of the cube of the new lattice is to

the side of the cube of the old lattice as $\sqrt{3}$ is to $\sqrt{2}$. Allowing for thermal expansion, the side of the cube of the old lattice at the point of transformation is about 2.90 Å, and the side of the cube of the new lattice will be about 3.56 Å, depending on the accuracy of the previous figure 2.90 Å. This result of 3.56 Å agrees well with

POLAR AXES
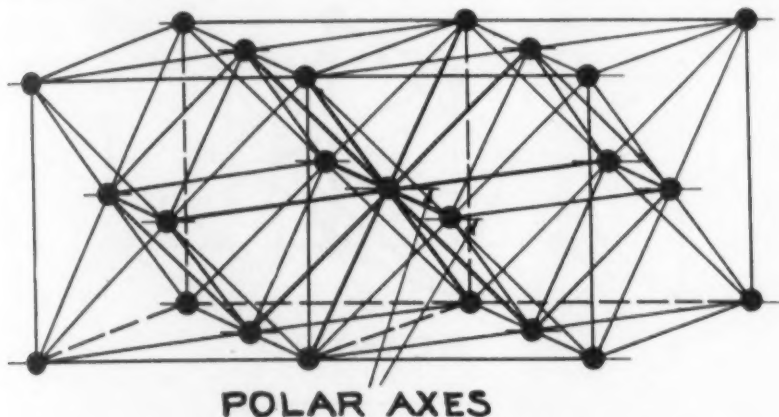
Fig. 5—Diagram of the Face-Centered Cubic Lattice. Here are Shown Two Cubes with the Lines of Force, of the Atom in the Adjoining Face, Indicated by Heavy Lines. The Lines Connecting the Corner Atoms of the Cubes do not Represent Lines of Force.

the available figure of 3.60 Å as the side of the elementary cube of gamma iron.

It is supposed that this change in the atom and lattice structure accounts for the changes observed at Ac_3 as follows:—

1—The face-centered cubic arrangement being a "closer" packing of the atoms, the change in space lattice, as explained above, is responsible for the physical contraction and is proportional to it.

2—The increase in heat content is due to the energy necessary for the change in the structure of the atom itself and the change of the space lattice.

3—Critical plasticity is caused by the movement of the atoms to their new positions, thereby causing the iron to approach close to an amorphous condition.

4—Grain refinement.—Fig. 6 represents the mechanism of change of beta to gamma iron. Here it will be seen that the octahedron of beta (or alpha) iron has merely elongated to form the octahedron of gamma iron, and it is suggested that the recrystallization will continue in the direction of this elongation as shown in Fig. 7. It is also suggested that on cooling the reverse

of this directional recrystallization gives rise, in iron-carbon alloys, to the metallographic structures of martensite, Widmannstatten structure, pearlite, etc.

In the grain of beta iron there is at the grain boundaries a layer of atoms, perhaps several lattice spaces in width, where the
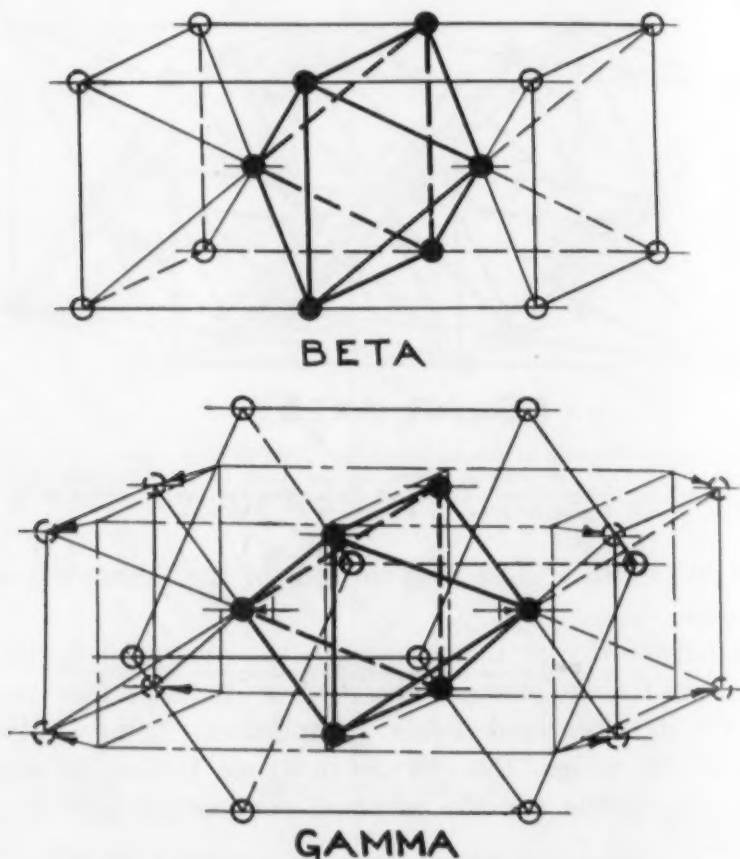
Fig. 6—Diagram Illustrating the Mechanism of Change of Beta to Gamma Iron. The Heavy Lines Connecting the Black Centered Atoms Outline the Octahedron. The Dot and Dash Lines in the Lower Figure Outline the Lattice of the Old Beta Structure.

lattice structure is distorted due to the different orientations of the adjoining crystals. Here, or at some other discontinuity, is the place where the change to gamma iron will first start, due to the state of "strain". The higher the temperature at which this change takes place the greater the number of starting points of recrystallization, (nuclei). For a certain velocity of recrystallization, the greater the number of starting points or nuclei the larger the number of new grains formed. Also the higher the temperature the greater is the tendency to grain growth after forming, and since

the new grains have grown from the old one it follows that they must not be a great deal different in orientation so that the tendency to grow is very great, and it is doubtful if the new grains of gamma iron remain "small" for any length of time.

6—The largely increased dissolving power of iron, above A_3, for carbon is probably due to the change of electromagnetic environment of the iron atoms on changing to the gamma state. This
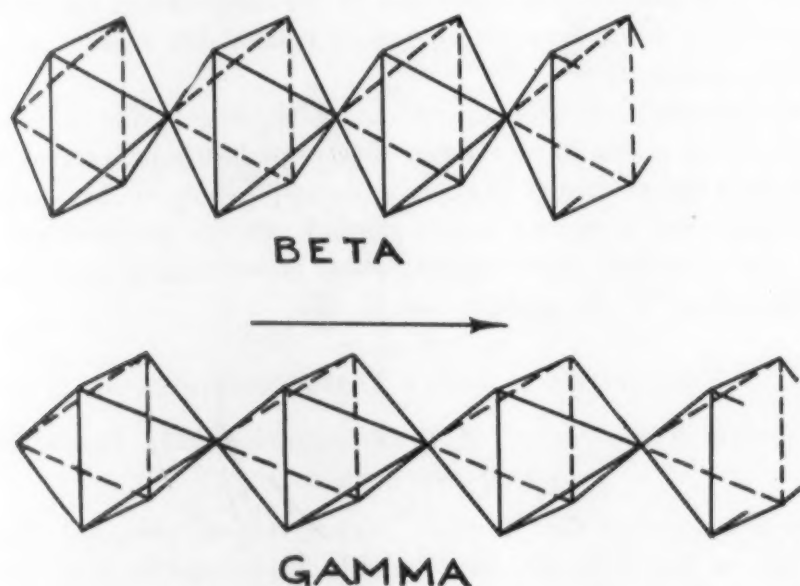
BETA

GAMMA

Fig. 7—Diagram Illustrating the Method of Directional Recrystallization. The Octahedra of Beta Iron Elongate to Form Octahedra of Gamma Iron.

theory as outlined by Harkins and King[3] postulates that the solubility of one substance in another—"can be predicted in most cases from the standpoint of the hypothesis that it is conditioned not only by the motion of the molecules (vibrations apparent as temperature, and probably rotations as well), but also by the intensity and the nature of the electromagnetic field surrounding them....If the stray fields around the molecules of (A) and (B) are sufficiently different in intensity, then the two substances will be practically insoluble in each other." That the electromagnetic environment changes at A_3 is evidenced by the change in magnetic susceptibility and the fact that the electrical resistivity of gamma iron changes very much less rapidly for differ-

[3]William D. Harkins and H. H. King, "An Electromagnetic Hypothesis of the Kinetics of Heterogeneous Equilibrium, the Structure of Liquids, and Cohesion," *Journal* of the American Chemical Society, June, 1919.

ences in temperature than the body-centered atom arrangement. Although the face-centered arrangement is a "closer" packing of the atoms, the electrons are very differently distributed than in the body-centered lattice, and a carbon atom in an octahedron of gamma iron can be placed much more symmetrically with, and further from, the iron atoms.

7—The increased tensile strength just above A_3 is due to the "closer" packing of the atoms and to the smallness of the grains.

8—The loss of ferromagnetism is caused for reasons as given above by Langmuir.

9—Noticeable hysteresis of Ac_3 with Ar_3 is due to physical inertia of the atoms in moving to their new locations, thereby tending to hold the electrons in their present positions. This condition exists until the electrons secure enough energy to break away to their new positions, with simultaneous absorbtion of more energy and movement of the atoms.

THE GAMMA TO DELTA TRANSFORMATION—A_4.

Equilibrium Temperature of Transformation 2552 degrees Fahr. (1400 degrees Cent.).

It is suggested that further heating so increases the thermal agitation of the 8 loosely held outside electrons that they become "without effect", or nearly so. (That is insofar as they tend to repel the other electrons or act as a means of directional application of the attractive and repulsive forces of the atom. In this condition they may be revolving around the nucleus or just vibrating with great amplitude.) so that the atom tends to revert to the structure shown in Fig. 8, which resembles that of the alpha and beta atom. It is proposed that on coming to the critical point Ac_4, it does revert to this structure with consequent change of the lattice structure to the body-centered cubic.

This change in the atom and lattice accounts for the changes at Ac_4 as follows,—

1—The change in the lattice for reasons given above.

2—The increase in heat content is due to the energy absorbed by the 8 outside electrons and the changing of position of the other electrons, together with the energy necessary to reposition the atoms themselves.

3—The decrease in tensile strength is due to the "looser" pack-

ing of the atoms and the fact that the 8 outside electrons are practically without effect, these influences are perhaps counteracted somewhat by any refinement of the grains.

4—Hysteresis with Ar_4 is due to physical inertia of the atoms in moving to their new positions as explained for A_3.

5—The increase in magnetic properties noted by some investigators is probably due to the change in the atom and space lattice, for reasons noted previously by Langmuir.

POLAR AXIS
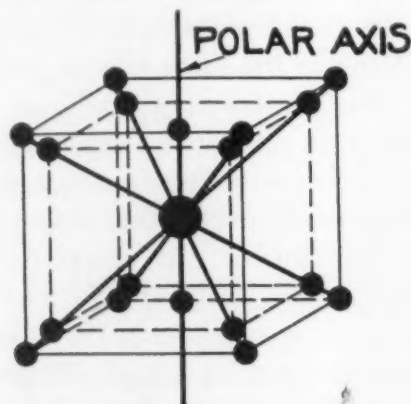
Fig. 8—Diagram of Proposed Delta Iron Atom (the 8 Outside Electrons are not Shown.) Here the 16 Inner Electrons are Again at the Corners of Concentric Cubes.

THE DELTA TO MOLTEN TRANSFORMATION

Temperature of transformation 2786 degrees Fahr. (1530 degrees Cent.).

It is suggested that the rise in temperature to the melting point is sufficient to so increase the thermal vibration of the remaining electrons, except perhaps the two nearest the nucleus, that they become ''without effect'' and disrupt the directional lines of force of the atoms so that the lattice structure breaks up and the iron becomes ''liquid.''

It is therefore proposed that the iron atom in liquid iron consists of the nucleus surrounded by the electrons which have no fixed positions and are more or less free to move.

This change in the atom and lattice accounts for the changes observed at the melting point as follows,—

1—The change from solid to liquid as noted above.

2—The large increase in heat content is due to the energy absorbed by the electrons in assuming their new state.

3—Since the change is within the atom itself and there is no moving from one lattice structure to another there is practically no inertia to overcome and hence the absence of hysteresis with the freezing point.

The transformations, with their causes and mechanisms, given for iron when heated are of course reversed when the metal cools.

It will be noticed that the lattice transformations of iron take place in the direction of the polar axes of the atoms and that the polar axes of the atoms in the same crystal are similarly oriented.

It is unlikely that on freezing the iron atoms assume any definite arrangement, with respect to their polar axes, in the lattice that is then built up, because of the fact that they can assume any one of three different positions, in this respect, with about equal ease. This disarrangement of the atoms is not conducive to stability and as soon as the structures of the atoms become sufficiently fixed there will be a tendency to re-orient themselves to their normal positions in the space lattice. If this tendency becomes strong enough there will be an entirely new set of crystals formed, preferably just below the freezing point. In any event, since the change from delta to gamma iron will take place with respect to the polar axis of the atoms, a new set of crystals will be formed without respect to the primary structure.

It is postulated that this is the cause and mechanism of the "granulation" of the primary dendritic structure.

In concluding the writer desires to express the belief that the crystal structure and properties of other metals may be similarly connected with their atom structure, and it is hoped to extend this theory to include the iron-carbon alloys.

LOCOMOTIVE PART FAILURES AND THEIR MICROSTRUCTURE

By F. H. WILLIAMS

Abstract

Failures in locomotive parts usually call forth an investigation which in many cases, after a cursory examination of the failure, amounts simply to an opinion as to the cause. When more thorough examinations are made, the microscope, physical tests and chemical analyses are resorted to.

The author has reviewed many types of failures which occur to locomotive parts and has given an analysis of the causes for failure in a few specimens. He points out the need for closer inspection, both of the raw material and the finished product, in railroad maintenance and construction work today.

A portion of the paper is devoted to a study of welded parts of locomotive construction and the manner in which its use can be abused. He then analyzes the use of the acetylene torch in the manufacture of locomotive parts, such as side rods, main rods and numerous other shapes. A study of the manufacture of locomotive frames is also made.

Throughout the paper the author has discussed the use of alloy steels and their application to locomotive building and has stressed the point that proper design, careful and accurate production, together with proper heat treatment and scrutinizing inspection are paramount.

Typical photomicrographs are included to illustrate the points developed in the paper.

THE failure of any part of a locomotive in service calls forth investigation as to its cause. The reason for such failure has very often been left to a mere visual examination of the fracture. Then in other cases, samples have been tested physically and microscopically and the determination of the cause of failure made from the results of that test. More accurate results are often

obtained when the chemical analysis of the material near the fracture is added.

The microscope has a special field of its own. Many times the methods of determining the cause of a failure have failed to give the true cause and it is in these cases that the microscope often points out the trouble and the remedy.

This would be too extensive a paper to even outline the many different defects in steel or in its heat treatment, that have caused failure in service. A few of the troubles in some of the parts of a locomotive have been described herein, and some of the better structures are shown. By no means are all phases of the situation covered in this short paper.

SIDE RODS—MADE FROM STEEL FORGINGS ANNEALED OR NORMALIZED

Various kinds of steel are used in locomotive side rods depending upon the requirements of the service which the design of the locomotive calls for. Alloy steels are becoming more common in the heavier types of locomotives.

Fig. 1 is a photomicrograph of a carbon steel side rod and Figs. 2, 3 and 4, of alloy steel structures as found in the commercial type of side, piston and connecting rods, respectively.

The carbon steel side rod was very poorly annealed whereas the others are fine-grained and uniform.

Physical properties of the steels shown in Figs. 2, 3 and 4 are as follows:

Tensile Strength	77,450 pounds per square inch
Yield Point	38,600 pounds per square inch
Elongation in 2 in.	29.0 per cent
Reduction of Area	57.1 per cent

Physical properties of the steels shown in Figs. 2, 3 and 4 are as follows:

	Fig. 2	Fig. 3	Fig. 4
Tensile Strength, pounds per square inch	99,400	125,400	97,000
Elastic Limit, pounds per square inch	62,800	. . . .	65,500
Elongation in 2 in. per cent	27.5	21.5	27.5
Reduction of Area per cent	54.8	55.8	56.1
Impact Value, Ft. Lbs.	37.9	60.6	..

ALLOY STEEL FORGINGS

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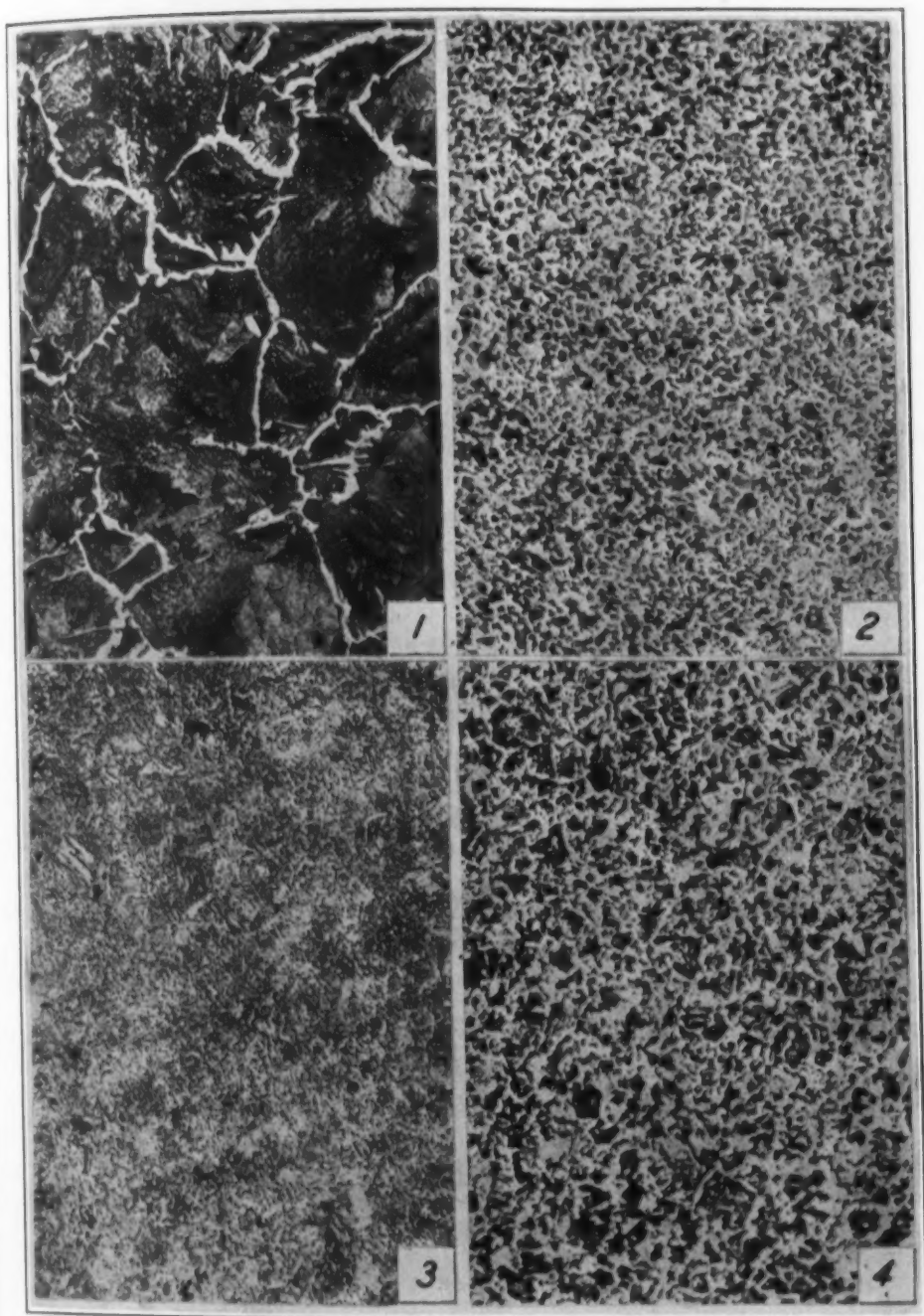
Fig. 1—Photomicrograph of a Carbon Steel Side Rod Which Failed in Service. The Structure is Coarse and Not Satisfactory. Chemical Analysis: Carbon 0.58 Per Cent, Manganese 0.68 Per Cent, Phosphorus 0.011 Per cent, Sulphur 0.032 Per Cent. ×100. Fig. 2—Photomicrograph of a Carbon-Vanadium Steel Side Rod. The Structure is Fine and Uniform. Chemical Analysis: Carbon 0.47 Per cent, Manganese 0.87 Per Cent, Vanadium 0.18 Per Cent. ×100. Fig. 3—Photomicrograph of a Nickel Steel Piston Rod, Heat Treated Before the Rod was Finished. Brinell Hardness 245. Chemical Analysis: Carbon 0.33 Per Cent, Silicon 0.15 Per Cent, Manganese 0.75 Per Cent, Nickel 3.32 Per Cent, Chromium 0.19 Per Cent. × 100. Fig. 4—Photomicrograph of a Nickel Steel Locomotive Connecting Rod. Specimen Cut from the Test Piece of a Front Connecting Rod. The Grain-size is Fine and Uniform. Chemical Analysis: Carbon 0.36 Per Cent, Manganese 1.22 Per Cent, Phosphorus 0.03 Per Cent, Sulphur 0.40 Per Cent, Silicon 0.28 Per Cent, Chromium 0.10 Per Cent, Nickel 2.23 Per Cent. × 100.

is a certainty. Owing to the cost of alloy steels there seems to be greater care taken of forgings of this class and therefore in this paper poor structures will not be shown for the reason that none have been submitted for examination.

The accompanying photomicrograph Fig. 5 shows the structure of a chromium-vanadium steel forging about 8 inches in diameter. There is very little to say about it save that it is of fine structure and very uniform.

The chemical analysis of the steel is as follows:

	Per Cent
Carbon	0.46
Phosphorus	0.015
Manganese	0.70
Sulphur	0.030
Silicon	0.19
Chromium	0.14
Vanadium	0.18

The physical properties are as follows:

Tensile Strength in pounds per square inch	96,300
Yield Point in pounds per square inch	63,500
Elongation in two inches, per cent	25.0
Reduction in Area, per cent	48.0

SMALL FORGINGS

Small forgings are often neglected as well as the large ones. There seems to be an idea among officials, that a forging can be annealed properly and that it can revert back to its original unannealed state, through stress in service, after a few years.

The necessity of properly annealed or heat treated forgings cannot be too strongly urged upon those that are in a position to have this done. Forgings of such importance as side rods, parts of side or main rods and crank pins should be annealed. Fig. 6 is a photomicrograph showing the original forging structure of a rough forging. This forging has been forged at too high a temperature and not enough grain refinement has been accomplished in the forging to make it satisfactory for the service it is to be used for. A side rod should be more uniform and of a much finer structure.

CRANK PINS OF LOCOMOTIVES

The failures occurring in locomotive crank pins is causing the
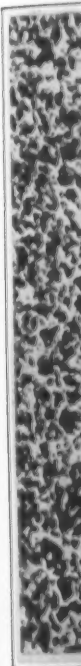
railways considerable anxiety. For the most part plain carbon steel has been used and it is on account of the failures that have occurred and the requirements of greater strength and less weight that alloy steels have been considered and tried lately.
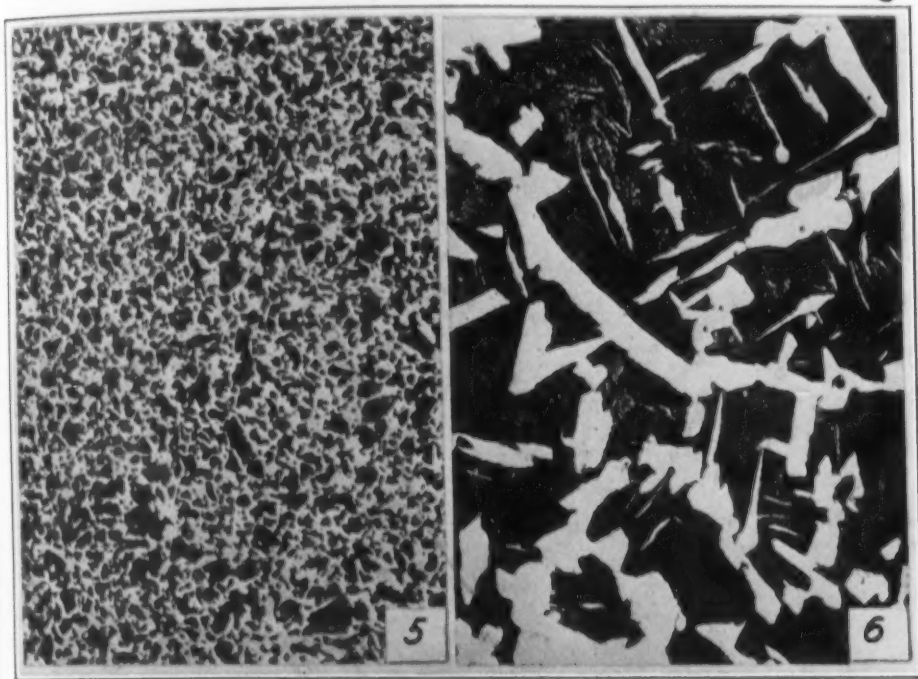
Fig. 5—Photomicrograph of a Chromium-Vanadium Steel Forging. × 100. Fig. 6— Photomicrograph Showing the Original Forging Structure of a Rough Forging. This Shows that the Forging Needed Annealing. × 100.

Properly heat treated carbon steel will do good work and shows an unusual resistance to final fracture.

Crank pin forgings that have not been properly annealed show quite a different type of fracture. Fig. 7 shows a fractured end off a crank pin that failed in service.

It will be seen that the metal gave away when it was but a little over half cracked through. The fracture is of the usual creeping crack variety due to fatigue of the metal and the final fracture is very coarse owing to the poor annealing that the pin received after forging. The manufacturers claim that the pin received the proper annealing and was satisfactory as to its physical properties.

When tested it was found that they were not so very far out as to the physical properties, but certainly they were in error as to
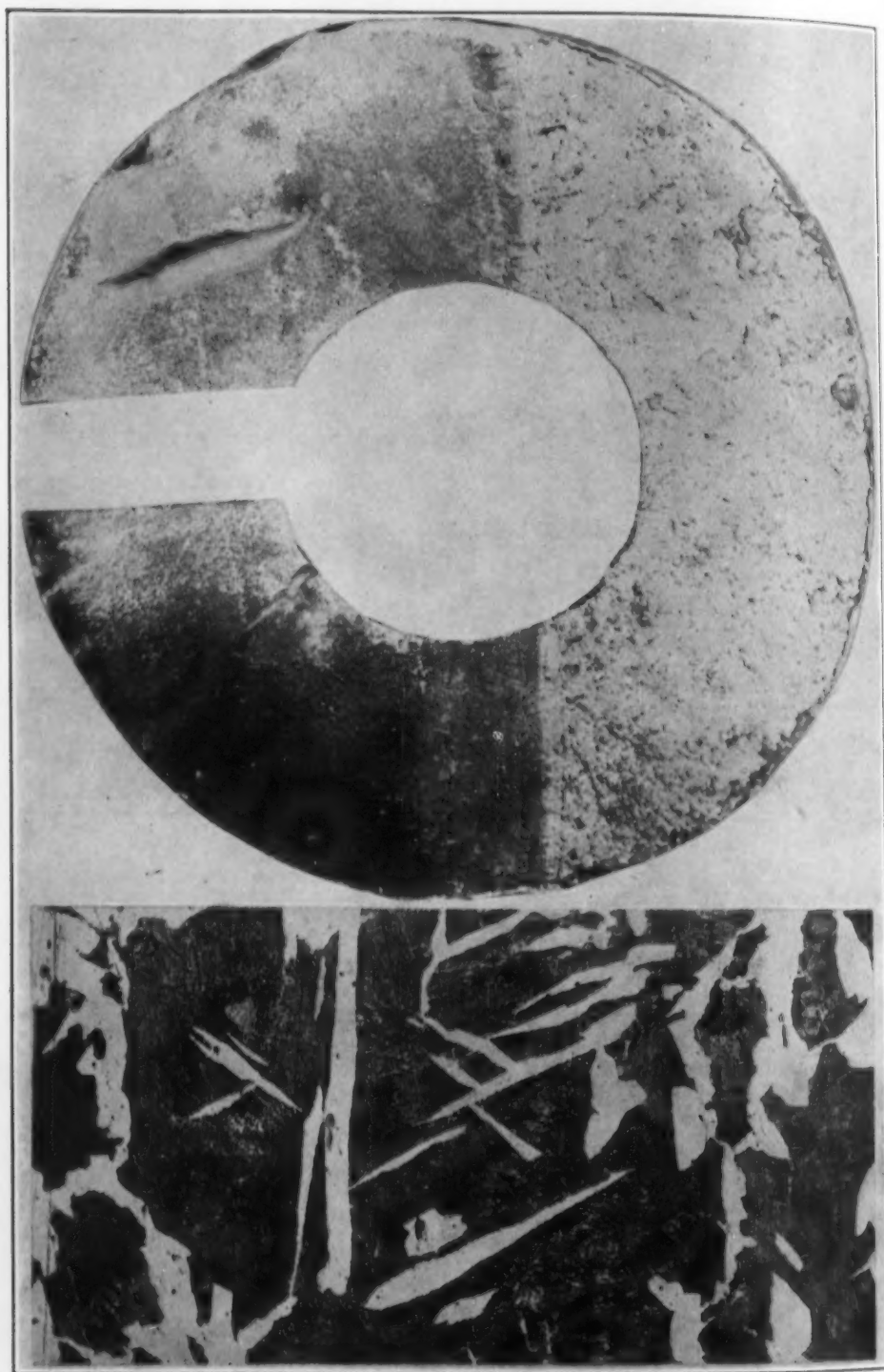
Fig. 7—(upper) Photomacrograph Showing the End of a Fractured Crank Pin that Failed in Service. The Fatigue or Creeping Crack is to the Left and the Coarse Final Break to the Right. Fig. 8—(lower) Photomicrograph Showing the Structure in the Supposedly Annealed Crank Pin above. Chemical Analysis: Carbon 0.45 Per Cent, Manganese 0.40 Per Cent, Phosphorus 0.019 Per Cent, Sulphur 0.028 Per Cent. × 100.

it being annealed. The physical properties of this steel are as follows:

Tensile Strength in pounds per square inch 79,130
Yield Point in pounds per square inch 51,800
Elongation in 2 inches, per cent 22.5
Reduction of Area, per cent 39.3

Fig. 8 shows the structure of the steel in this pin. It is very coarse and indicates very clearly that it was not annealed.

WELDING OF STEEL FORGINGS

The use of welding on parts of locomotives is often carried to extremes and the result is failure. It is surprising how many such jobs are done and how many times they fail. Perhaps some machinist has taken off too much of a cut on an expensive forging and away he goes to the welder to help him out. Often this work is done on his own responsibility and very often it is done with the approval of a foreman or superintendent. Then again the blacksmith has made a job wherein he has not left enough stock to finish up clean on a bearing or where it will be seen and off he goes to the welder.

It would be impossible to go into this subject as completely as one would like in a paper of this kind. The writer will show some of the characteristics of the material and weld after a poor job has been done. A poor job is the one that fails to get by. The writer believes that it would be interesting to see some examples of good and poor welding, hoping that it will benefit and promote better welding and also reduce the attempts to weld too high carbon steels when the part is for work that requires strength, unless the plant is properly equipped for the work and the workmen understand what is necessary to be done to accomplish this. Therefore Figs. 9, 10, 11 and 12 are presented. It must be understood in the first place that the deposited metal is of a cast nature, that it is of a low carbon steel and that it is not generally subjected to mechanical treatment. Therefore why expect a metal equal to the original steel to which it is applied? Some shops do give the welds mechanical treatment during the welding operation and therefore reduce the strains in the weld; the weld is peened after each length of electrode is used.
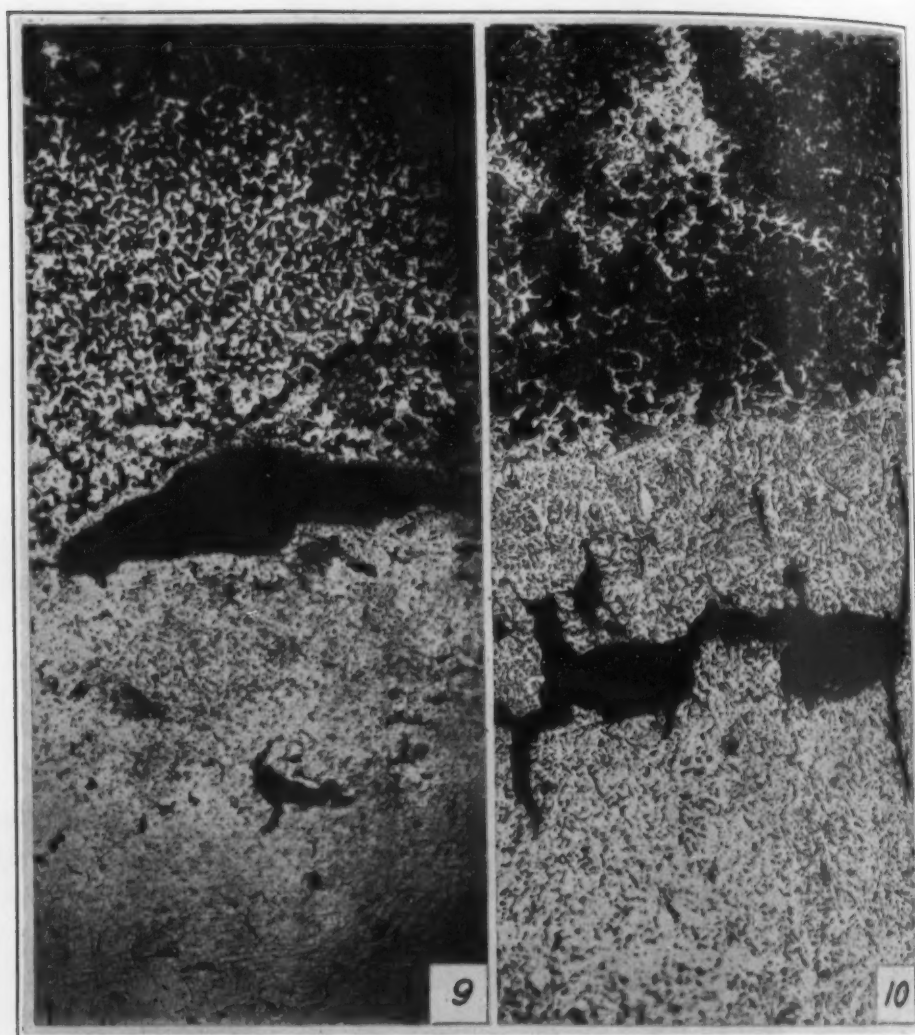
Fig. 9—Photomicrograph of a Weld on a Forging. This Shows that the Piece was not Annealed after Welding. It also Shows that there were Flaws in the Weld and that Cracks were Developed on Cooling. The Deposited Metal is Shown at the Bottom. × 100. Fig. 10—Photomicrograph Showing the Course of a Fracture Starting from a Flaw in the Welding. The Fracture Passes Through the Deposited Metal a little Away from the Point of Fusion of the Deposited and Parent Metal. × 100.

Fig. 9 shows the structure of a weld and the cracks that follow a poor welding job.

Enormous savings can be made by railroads through the proper use of acetylene, electric and thermit welding. The use of resistance and other electric and gas welding processes also add to the saving. One specially important case is the welding of safe ends on boiler tubes, hundreds of thousands of such welds are made without failures and the speed attained is far ahead of the old
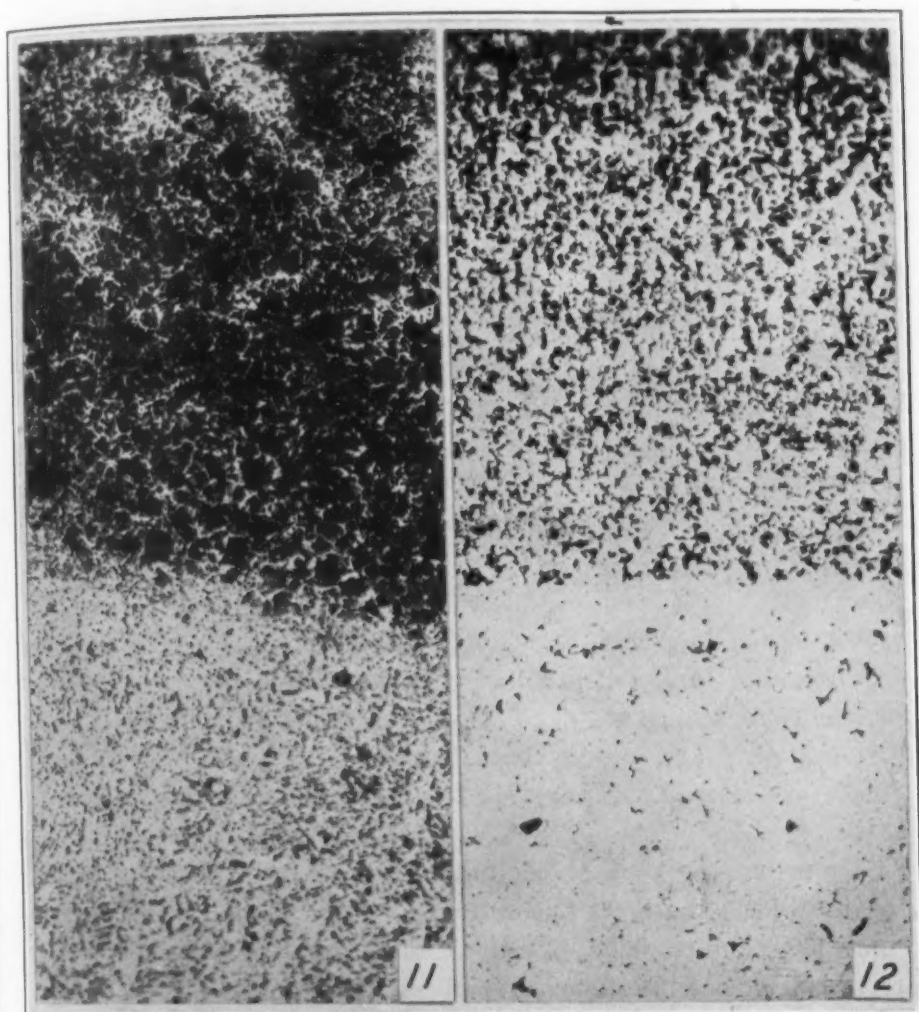
Fig. 11—Photomicrograph Showing the Structure of the Best Part of a Weld. The Effect of the Heat of the Arc is Shown in the Refinement of the Grain from a Coarse Structure to a Fine Structure. The Deposited Metal is Shown on the Bottom. × 100. Fig. 12— Photomicrograph Showing a Good Weld. The Work Should be Annealed After the Weld is Made and Before it has Cooled Enough to Set up Small Cracks that in time will Cause Failures. × 100.

furnace heated welding process. Space does not permit the inclusion of structures of such welds, but they are certainly superior to the old ones.

Small forgings are often worn out when the locomotive comes in for repairs and enlarged bolt holes are filled in and rebored. On very thin sections this is readily accomplished but where the depth of the hole is two inches or more, care is necessary to make a good job and sometimes it is not done. This forging, illustrated with the

accompanying photomicrographs, was only 1¾ inches thick and was forged at a high temperature and not annealed. It was then repaired as above described.

Part of the filling in was good, the penetration satisfactory. For the most part however it was poorly welded and the deposited metal was more or less a bushing of soft low carbon steel. The failure took place through this poorly repaired bolt hole.

Poor work such as this increases the liability of the forging to fail. Figs. 9, 10, 11 show the various structures at the weld. Fig. 12 shows the structure of a good weld, which can be made if the proper care is taken.

Cutting out Side Rods and Other Shapes From Forgings With the Acetylene Torch

(Mechanically operated.)

The use of the acetylene torch in the cutting of shapes from rough forgings constitutes a practice that saves the railways considerable time and money. The shapes that can be economically cut in this way are many, consisting of both plain and intricate patterns. A few of the parts of the locomotive fabrication are as follows:

Side rods, main rods, large and small washers and filler pieces, links, link blocks, hangers and numerous other shapes, extensions to engine frames, etc. The practice has practically no limit to its usefulness as a safe, economical time and expense saver.

Like everything else in new ideas and practices, care must be taken not to carry it too far and expect too much from it. For example the use of the torch on forgings of alloy steel is very hazardous and should be avoided. Incipient cracks are sure to occur and failure sure to result therefrom.

The use of the torch on medium carbon steel forgings is one that requires care, the higher the carbon content the higher the intelligent handling of forgings should be. The forging should first be preheated to about 1200 degrees Fahr. and then placed on the cutting table and cut to shape as quickly as possible, then replaced in the annealing furnace and annealed at a temperature of about 1500 degrees Fahr. or the proper temperature for the carbon content of the steel that the forging was made of. The forging
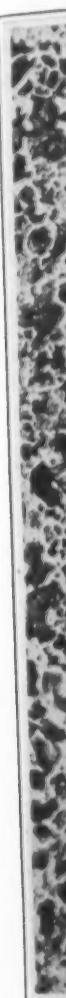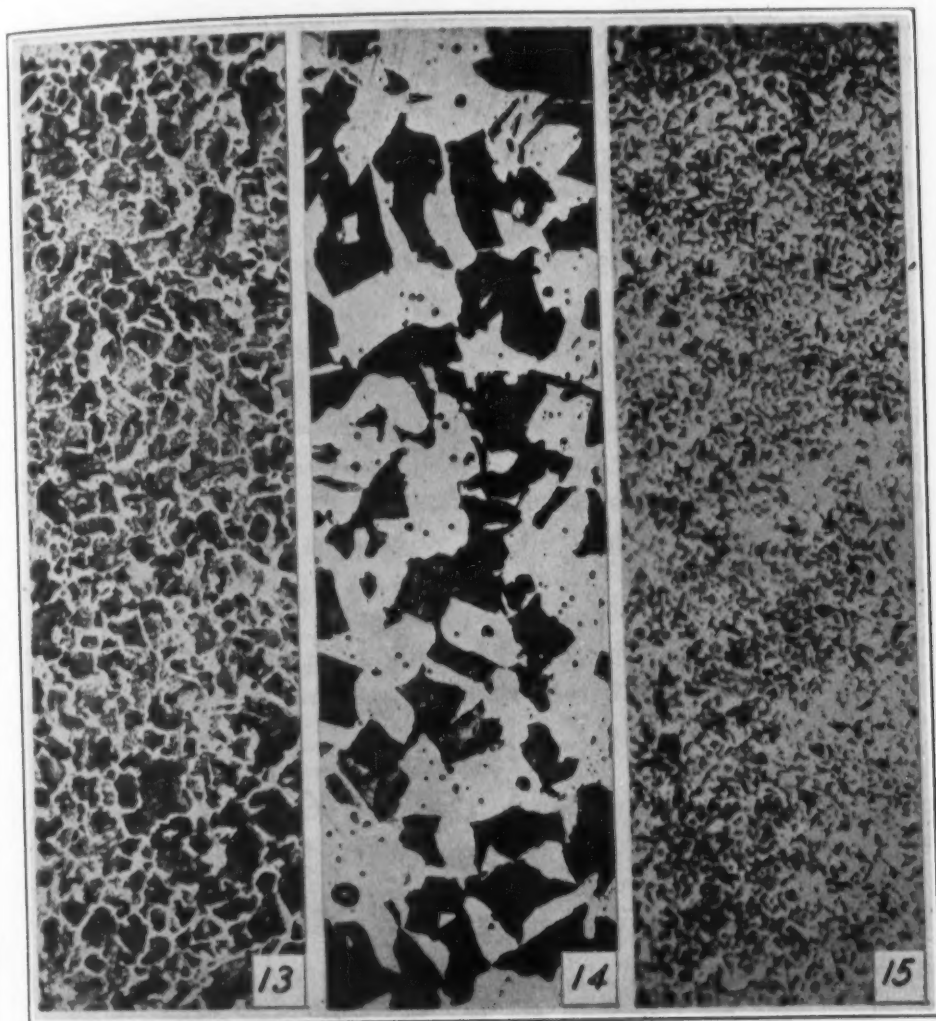
Fig. 13—Photomicrograph Showing the Structure of a Side Rod Cut out with the Acetylene Torch and Annealed at 1600 degrees Fahr., in an Oil-Fired Furnace. ✕ 100. Fig. 14—Photomicrograph Showing the Structure of a Carbon Steel Locomotive Frame. The Structure is Coarse. ✕ 100. Fig. 15—Photomicrograph of a Carbon-Vanadium Steel Locomotive Frame. Grain Size is Fine and Uniform. The Coarse Casting Structure has not been Completely Scattered. ✕ 100.

should be cut at a temperature of not less than 1000 degrees Fahr. and if handled quickly there will be no difficulty experienced if the forging is 1200 degrees Fahr. when taken from the furnace.

The cutting of high carbon steel is attended with considerable danger similar to that experienced with alloy steels and should be avoided.

Forgings in the rough have a very coarse grain unless forged at a low temperature and when cut to shape by the torch they have

a very complex grain structure, starting at the surface and continuing in for about ¼ inch or more in depth. To have the finished forging of a uniform structure throughout, annealing, or normalizing if desired, should be carried out carefully and conscientiously. Most parts, such as side rods, engine frames, etc., should be machined after they have been annealed to remove the rough edges to avoid failures, and fine cracks if any should have been developed in the operation of cutting.

The amount of work a man and helper can do with a cutting machine and annealing furnace is enormous and well worth considering in shops where there is much of that work to do. This refers to the cutting and annealing operation only and does not include the rough forging. A great saving on the forging end in the blacksmith shop is naturally affected.

To illustrate the necessity of annealing after cutting; photomicrograph Fig. 13 is included herein to show the microstructure of the steel in a side rod as cut and annealed at 1500 degrees Fahr. The structure is uniform and of fine grain throughout, the coarse forging structure is entirely removed as well as the mixed structures due to the cutting.

While the strains may be somewhat removed by a heating to 1200 degrees Fahr. no change in the grain size is accomplished. A temperature of 1450 to 1550 degrees Fahr. should be used depending upon the carbon content in order to obtain the proper grain refinement and uniform structure; allowing about one half hour per inch of thickness of the forging.

LOCOMOTIVE FRAMES

Locomotive frames are made of cast steel. Up until recently carbon steel was most used, then carbon-vanadium and then nickel steel.

At first, considerable difficulty was experienced in casting alloy steel frames that would be free of cracks, pipes and flaws. These difficulties were overcome and now alloy steel frames are being used to quite an extent.

Carbon steel frames are satisfactory up to the large section frames, when the use of alloy steel is necessary. Careful check should be maintained on the annealing of carbon steel frames and the normalizing of alloy steel frames in order that the structure of

the steel be sufficiently fine-grained to ensure satisfactory castings.

That this is often neglected, will be demonstrated in the photomicrograph Fig 14, showing the structure of a carbon steel locomotive frame. The photomicrograph shows that the casting structure has not been removed.

Carbon-vanadium steel frames of large section, viz., 5 and 6 inches thick show up very fine uniform structure in the coupon attached to the frame for test purposes. Photomicrograph Fig. 15 is the structure of such a frame. The grain is fine and uniform.

The physical properties of the carbon-vanadium steel frame are as follows:

Tensile Strength, pounds per square inch	84,900
Yield Point in pounds per square inch	47,000
Elongation in 2 inches per cent	27.0
Reduction of Area per cent	47.0

	Per Cent
Carbon	0.32
Manganese	0.78
Phosphorus	0.043
Sulphur	0.039
Silicon	0.33
Vanadium	0.22

CONCLUSIONS

In concluding this paper the writer would suggest that anyone interested in iron and steel, give some time to the study of the microstructure of the parts going into the locomotive, and in fact into any equipment that they are accustomed to handle and it is surprising how much there is to learn and how much can be saved by even this study.

The designers of equipment should have an even greater knowledge of the structure of steel and its treatment than the average designer has. The old adage: "Eternal vigilance is the price of liberty" is a good one in the iron and steel business. There can be no let up to the study if one wants to avoid pitfalls.

The foregoing photomicrographs will illustrate this in no small degree if one takes time to consider that there are practically no two alike. Does this mean that they are all good or all bad? No! It means that one has to be careful and determine what is good and then to insist that it be obtained. The designer takes time to see that his drawings are correct to 1/1000 of an inch, plus

or minus and then someone supplies him with material that is not within 1/1000 of what he expects to get. The heat treatment is out, the machining is bad or the case is too thin, and in the grinding the case is more than removed. "Like breeds like," in heat treatment as elsewhere and indifferent attention to heat treatment of steel castings and forgings will certainly result in indifferent steel and unsatisfactory service.

DISCUSSION

Written Discussion: By J. M. Watson, Hupp Motor Car Corp., Detroit.

In Mr. Williams' paper I notice that in discussion of the parts which failed, with the exception of the springs, practically all of the material used is straight carbon steel. On some of the springs chromium-vanadium steel is mentioned, and I would like to ask whether there is any tendency for the railroads to go to alloy steels in order to get increased strength and also to allow the reduction of weight in some of the more important parts. This has been the tendency in automobile design during the past years, and it would seem to be the logical procedure for the railroads to follow.

It may be that the high speeds used in passenger traffic makes it necessary to have the present heavy weight of equipment, but it would seem that great savings in fuel cost could be made by using alloy steels.

Written Discussion: By E. E. Thum, The Iron Age, New York City.

I would like to ask Mr. Williams to explain his understanding of the term "crystallized metal." You may know that most failures of parts in service are blamed on "crystallized metal" by the ordinary mechanic. This term implies that the structure of the metal has been changing during the time the piece has been in service, whereas the fact is that such a change in steels at room temperature does not take place.

Author's Reply to Discussion—Replying to J. M. Watson: there is a tendency on the part of railroads to go to the use of alloy steels for increased strength and reduction of weight. The use of alloy steels to reduce weight and size of section must be carefully studied because lighter sections may have the strength but their stiffness may be sacrificed and many failures may result from fatigue cracks owing to this lack of stiffness. Modern machining speeds, together with the lack of proper stiffness is a bad combination as machining grooves or tears may start failures.

I am sure that great savings can be made by the use of alloy steels, but the change must be carefully made and the parts carefully designed and heat treated.

Replying to E. E. Thum: the grain-size of metal does not change during the time the part is in service, provided the piece retains its same form and is not overheated. If the form is lengthened or otherwise changed the grains or crystals will change in form but they will not grow.

Generally speaking a progressive fatigue break is looked upon by shop men as a flaw, or that the material wherein it occurs is of a finer-grained metal than the rest of the section; in other words the forging has been unevenly heat treated.

SOME EFFECTS OF HEAT ON THE PHYSICAL PROPERTIES OF STEEL

By John L. Cox

Abstract

This paper describes the phenomena occurring in tensile tests of steel with rising temperature, together with the appearance and effects of "creep."

It shows the impossibility of making short-time creep tests and the necessity for accurate knowledge of the proportional limit if long-time tests cannot be made.

It shows the necessity of extreme accuracy in every element involved in the determination of the proportional limit at elevated temperatures and the attendant difficulties.

It discusses the application to design of experimental results and gives a short description of manufacturing methods for producing weldless pressure vessels for high temperature work for the guidance and information of designers.

ALTHOUGH the investigation of the properties of metals at temperatures above the normal was begun long ago, the subject was more or less of academic interest and the present intensive search for information did not begin until the advent of the steam turbine, the internal combustion engine, and modern chemical processes involving high pressures at elevated temperatures. These made the possession of such knowledge imperative.

I shall not attempt to trace the historical progress of this research, inasmuch as it has been ably done by V. T. Malcolm, whose paper on the subject read at Cleveland in 1924[1] is full of information and of interest. To his list, however, I should like now to add the names of Chevenard, Portevin, Bouasse, Lynch, Mochel, McVetty, Ingall, Henry, Pomp, Dahmen, Cournot, Sasa-

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gawa, Kirsch and Bayley, all of whom have done work of out-
standing merit at the date of its accomplishment.

It was natural that at first nearly all the work done was upon
short-time tests as paralleling the accustomed determinations at
atmospheric temperatures. It was learned that the tensile strength,
the yield point, the proportional limit and the modulus of
elasticity generally varied inversely with the temperature, and
attempts were made to find formulæ for the functions involved.

Elastic extension was carefully studied. The influence of
speed of deformation upon the results of tensile tests received much
attention, as did also the effect of grain size. Determinations of
the characteristics of many metals over wide ranges of tempera-
ture were made and reported. This information was welcomed
by engineers who felt then a confidence in the figures they could
use for allowable stresses, having thitherto been obliged to use
excessive factors of safety to counterbalance their lack of
knowledge when dealing with materials working at high tempera-
tures.

In 1922 J. M. Dickenson reported to the British Iron and Steel
Institute the results of tests he had made at elevated temperatures
and for extraordinarily long periods, reaching thousands of hours.
He showed that at loads far below the proportional limit, as then
determined for a material at a given temperature, there occurred
a slow plastic flow which might ultimately produce fracture. As
engineering constructions subjected to heat are usually maintained
at temperature over long periods of time, this work of Mr. Dicken-
son aroused great interest. Doubt was at once thrown on the
reliability of all previous determinations of proportional limit and
the new line of investigation was followed with feverish haste.

It is evident that where one test may take thousands of hours,
or five years in the case of some tests recently reported by Dr.
Rosenhain, the number of possible tests that can be made is cor-
respondingly reduced. Hence a common aim has been to find some
way by which the results of a short-time test could be correlated
with a long-time test for any given material and thus render the
long continued test unnecessary. Now this sounds easy, but it has
proved very difficult.

Let us consider for a moment the phenomena occurring when
a static test is made at a temperature sufficiently elevated. Accord-

ing to the material, the temperature and the load, the shape of the time-strain curve will vary, but this curve will illustrate what I want to show (Fig. 1.)   The illustration is borrowed from a most interesting article by Michel and Matte in *Revue de Métallurgie* for April, 1927.   In the graph ab is the instantaneous elastic elongation, the piece recovering its length immediately on removal of the load,
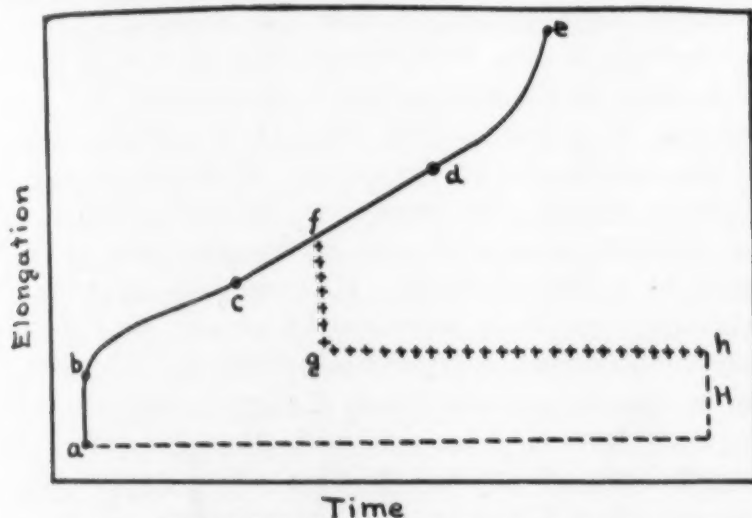
Fig. 1—Elongation-Time Curve Determined by Static Test at Elevated Temperature.

equal extensions occurring for equal loads throughout this distance: bc is a slow elongation at decreasing speed, partly elastic and slowly recoverable, partly permanent.   This is creep within the strain hardening range.   The straight line cd is a slow elongation at constant speed.   Maintained sufficiently long, the accompanying contraction of area increases the stress per unit of area, necking occurs, and at a certain limiting stress a rapid flow begins at d, followed by fracture at e.   The flow bc, at retarded rate, occurs only in the range permitting increase of strength through strain hardening or cold working, so-called.   If the strain hardening increases the strength of the steel to equal the stress, cd becomes horizontal and the stress can be carried indefinitely.   If the temperature is such as continuously to temper the hardness tended to be produced by the strain hardening, bc may not appear at all. The point b corresponds to the proportional limit; c to the "limit of plasticity" of Michel and Matte, or the "beginning of secondary flow" of French.   From what has been said it is evident that they may coincide or be separated, according to circumstances.

If a piece be stressed below b there should be no permanent deformation no matter how long the stress be applied, supposing that the material had originally perfect elasticity. Beyond b there will be deformation, but life will be indefinitely long if cd be horizontal. The angle cd makes with the vertical axis is an indication of the life if the limit of plasticity be passed.

As stated, it is probable that no material has perfect elasticity because it has been found that a torsion pendulum made of a wire or filament of glass or of steel, for example, oscillating in a vacuum, even very slowly, will with time decrease the amplitude of its beat. This shows that some of the initial energy has been lost through friction of the molecules or larger structural units of the substance, which therefore cannot be perfectly elastic. However, this departure from perfect elasticity cannot be measured by grosser methods and for all ordinary engineering applications perfect elasticity can be assumed up to the proportional limit. Following the results of this procedure, Mr. Chevenard has produced alloys for springs having reduced coefficients of internal friction which have notably improved the accuracy of watches and chronometers.

A great many methods have been followed by experimenters upon this problem, the four principal being to:

1. Hold the piece at constant load, and vary the temperature.
2. Hold the piece at constant temperature and decrease the load in proportion as the section becomes reduced by contraction.
3. Hold both temperature and load constant.
4. Hold temperature constant and increase load as creep stops.

The results obtained by these several methods are not altogether comparable or concordant. Of the four, the third method most nearly agrees with the working condition of engineering members, and the results obtained by it are, to my way of thinking, those that should be followed in practice.

Mr. Bouasse has said, "the fundamental characteristic of permanent viscous deformations consists in this, that the force which opposes the deformation is a function of the time."[2] In any short time test for determination of "limit of plasticity," the impossibility of pulling a test in a few minutes, so as to approximate

[2]*Aciers Spéciaux et Leurs Emplois.* Vol. II, No. 25, September, 1927, p. 479.

the slow flow of long-time tests, renders the result valueless, as yielding a figure altogether too high.

The drop of the beam of a testing machine, marking the yield point of a cold specimen, occurs after plastic deformation has begun. The point is much less marked, and the effect of plastic flow much greater as the temperature rises, which makes the yield point in many elevated temperature experiments of little practical value.

As the temperature rises its effects become increasingly greater. This requires extreme accuracy in measuring and controlling the temperature, if results of much value are to be obtained. Not only is it very difficult to secure continuity of the desired temperature, but it has been found that it is perhaps nearly as difficult to secure uniformity of temperature along the stem of the test piece. Much progress has been made, lately, in the design of equipment to secure uniformity of heating, but the difficulty of fluctuations in the electric current used for heating generally remains to give trouble.

The perfect alignment and accuracy of the testing machine is of great importance. An error of 0.01 inch in alignment has been found to produce an error of 15 per cent in the results of a standard 0.505 inch diameter test bar.[3] The ordinary allowance of $1\frac{1}{2}$ per cent error in the readings of commercial testing machines, not of great importance in cold testing, becomes more serious when values are rapidly changing.

Finally, the determination of the extension for definite loads, upon which depends the evaluation of the proportional limit, requires increased accuracy in proportion as the temperature rises. The stress-strain diagram no longer shows a more or less abrupt change of rate of elongation; the departure from rectilinearity occurs by almost imperceptible amounts. The curves by McVetty shown in Fig. 2 exhibit clearly this difference of form.[4]

At low or moderate temperatures, where strain-hardening could care for a slight overload by strengthening the steel to withstand it, the highest degree of accuracy is not so essential; but above the point where strain-hardening can occur, as a slight overload will produce ultimate rupture, the greatest possible accuracy is required.

[3]McVetty and Mochel, TRANSACTIONS American Society for Steel Treating, Vol. XI. No. 1, January, 1927, pp. 84, 86.

[4]Lynch, Mochel and McVetty. *Proceedings* American Society for Testing Materials, Vol. 25, Part II, 1925, page 10.

Take the case of the test diagram Fig. 3 by McVetty at 400 degrees Cent.[5] If one-thousandth of an inch is the smallest observable movement of the extensometer, 23,000 and 83,000 pounds per square inch respectively, would be taken as the proportional limits of the normalized medium carbon steel and the heat treated stainless iron; while if the instrument be read to one-millionth of an

Temp °C	Proportional Limit Lbs/Sq In	Yield Point Lbs/Sq In	Modulus of Elasticity-Million Lbs/Sq In
25	65000	106000	30.1
100	66500	99000	29.2
200	62500	97500	29.8
300	62500	96000	28.0
400	45000	88500	25.4
500	10000	62500	23.2
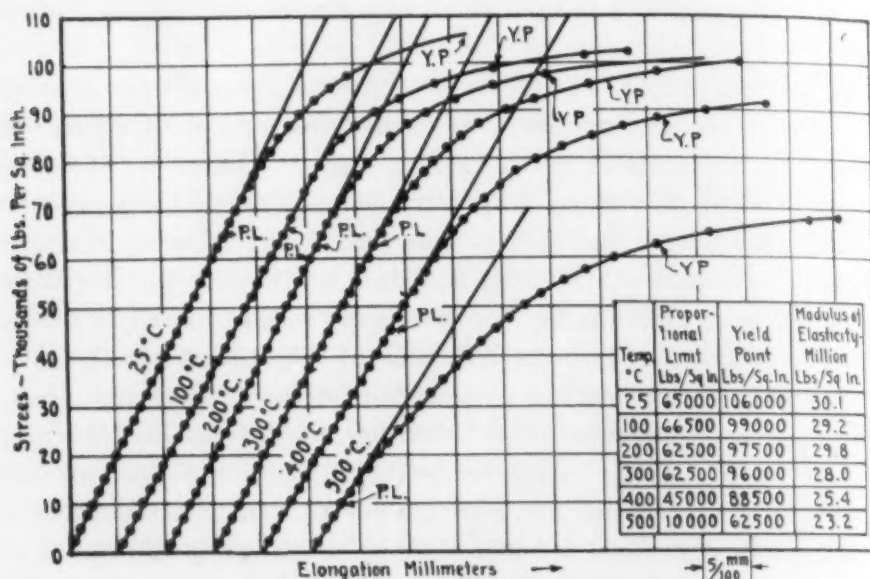
Fig. 2—Elongation-Stress Curves at Various Temperatures as Determined by McVetty.

inch, the figures become 15,000 and 27,000 pounds per square inch.

Clearly, the position of the proportional limit depends largely upon the extreme accuracy of the extensometer, which in the modified Martens mirror instrument is to one one-millionth of an inch, or even to one half that figure.

So far, experiment has shown that the effects of strain-hardening, at a maximum at ordinary temperature, decrease with rising temperature to 0 at about 750 to 800 degrees Fahr. (400 to 425 degrees Cent.[6] Above this temperature, then, to be of value, experiments must be exact. Could we measure more closely than the one-millionth of an inch, it would be highly desirable, although such refinement of measurement should be accompanied by a corresponding accuracy of loading and of temperature control. Ac-

[5]McVetty and Mochel. Transactions American Society for Steel Treating, Vol. XI, No. 1, January, 1927, p. 88.

[6]French, *Proceedings* American Society for Testing Materials, Vol. 25, Part II, p. 40.

curacy in one element must be accompanied by accuracy in the others.

Very careful tests made by the Westinghouse engineers and by the Bureau of Standards have shown that where the proportional limit had been determined with proper precautions to one-millionth of an inch per inch, long-time tests made slightly below
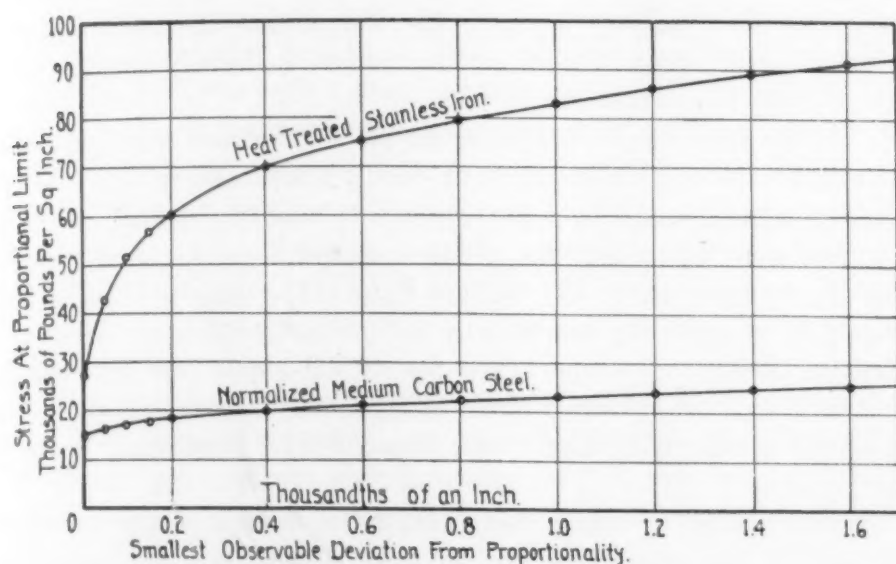
Fig. 3—Curves Showing the Relation at 400 degrees Cent., Between Stress and Smallest Observable Movement of Extensometer as Determined by McVetty.

that point gave no evidence of plastic flow, whereas those made slightly above the point showed it. Therefore, I conclude that only those short-time determinations of proportional limit made by the most careful laboratories and to the millionth of an inch per inch in extension can be relied upon for practical use above 750 degrees Fahr. Should two such results differ, it is safer to take the lower figure.

The curves for a wide range of steels at ascending temperatures have been published. Each has its peculiarities, and it is difficult to generalize because of the exceptions. However, one may say that of most steels the tensile strength, proportional limit and modulus of elasticity are greatly reduced by heat, while the ductility is correspondingly increased. To quote French and Tucker, "certain combinations of composition and treatment, notably normalized chromium-vanadium, quenched and tempered stainless, and air-cooled 28-per cent nickel steels are strongest

at ordinary temperatures, but carbon and the majority of alloy steels show maximum tensile strength and minimum ductility in the range 400 to 650 degrees Fahr. (205 to 350 degrees Cent.).[7] It might be expected that minimum ductility and minimum reduction of area would occur at the same temperature with maximum tensile strength since the breaking area would be largest, but this is by no means always the case. The minimum elongation is likely to occur at a slightly lower temperature than the minimum contraction, and the minimum contraction at a slightly lower temperature than the maximum stress.

If the steel has been normalized or cold-worked a rise in tensile strength is likely to occur with rising temperature, but it is not usually accompanied by a corresponding rise in proportional limit. In most heat treated steels, whether or not there be an increase in tensile strength about 525 degrees Fahr. (275 degrees Cent.), there rarely is, if ever, any increase in the proportional limit. Above this limiting range of temperature nearly all steels lose both tensile strength and proportional limit at a steadily increasing rate. The modulus of elasticity also drops steadily with increasing temperature.

The extent to which heat treatment increases the resistance of steel to the softening effect of heat is not yet well understood. In the lower ranges of temperature up to about 800 degrees Fahr. (427 degrees Cent.) there is no doubt that such treatment is effective, and I believe it to be effective up to, or nearly up to, a temperature (long applied) which would remove, in a cold test, the hardening effects of the preceding quench.

If the tempering temperature had been applied for a short time only, the effect of a lower temperature of tempering for a long time might be marked. Thus one gets the same temper color, dark blue, with an hour's tempering at 490 degrees Fahr. as one gets with about an 8-minute tempering at 660 degrees Fahr.; and the first set of temper colors is a very fair measure of hardness. Of course I do not mean that one hour is a long tempering. On the contrary, it is a very short one.

French and Tucker[8] place the limit of temperature at 1100 degrees Fahr. beyond which initial high proportional limit due to

[7]The Effect of Temperature upon the Properties of Metals, 1924, pp. 57, 59.

[8]The Effect of Temperature upon the Properties of Metals. *Proceedings* American Society for Testing Materials, Vol. 24, Part II, 1924, p. 62.

treatment is lost. Mochel and McVetty give 930 degrees Fahr. (500 degrees Cent.) as the temperature where most of the treatment effect of 5 per cent nickel and stainless iron is lost.[9] For some steels, I feel well assured it is decidedly higher, probably not under 1200 degrees Fahr. (650 degrees Cent.), although I have not yet curves for this material. Above this range, for most steels ending about 1100 degrees Fahr. (590 degrees Cent.), for some special steels perhaps extending 200 degrees Fahr. (92 degrees Cent.) higher, recourse must be had to steels so high in alloys that they are hardly still to be called steel. Such a metal is BTG alloy of the Commentry-Fourchambault et Decazeville Co., invented by Girin and having about the following composition, or as modified by Hadfield, English licensee;

Carbon	Manganese	Silicon	Nickel	Chromium	Tungsten
0.32	1.35	0.12	60.0	12.00	2.25
0.45	2.00	0.40	58.0	11.25	4.00

This alloy carries the highest loads of which I know in actual use. It finds employment in autoclaves, catalyst chambers, etc., where both high pressure and high temperature must be supported. In practical use good cast vessels of this material have lasted from 3000 to 10,000 hours carrying a load of 23,000 pounds per square inch at 972 degrees Fahr. (500 degrees Cent.). Many have lasted 20,000 hours.

For an alloy—carbon 0.35 per cent, manganese 1.25 per cent, silicon 1.0 per cent, nickel 26.0 per cent, chromium 14.0 per cent, tungsten 4.0 per cent—Hadfield claims indefinite life under 17,600 pounds stress at 1112 degrees Fahr. (600 degrees Cent.), but the French consider the B.T.G. metal better.

A set of curves has recently been obtained by H. J. French of the Bureau of Standards and will probably be issued in the near future[10]. The steels tested are ordinary boiler plate, carbon 0.24 per cent; a carbon 0.39 per cent, chromium 0.87 per cent, molybdenum 0.21 per cent, alloy steel, normalized, oil-quenched and tempered; a stainless steel, carbon 0.28 per cent, chromium 20.5 per cent, water quenched and tempered; a carbon 0.21 per cent, chromium 18.0 per cent, nickel 23.4 per cent steel, tempered at

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[9] TRANSACTIONS American Society for Steel Treating, Vol. XI, No. 1, January, 1927, p. 75.

[10] Creep in Five Steels at Different Temperatures, Technologic Paper 362, U. S. Bureau of Standards.

1450 degrees Fahr. in the furnace; and finally a carbon 0.77 per cent, chromium 3.9 per cent, tungsten 13.6 per cent, vanadium 1.9 per cent high speed steel, probably annealed. The curves show the loads that can be borne by these several grades of steel at rising temperatures for several percentages of initial plastic flow or creep, and the loads that can be borne for 1000 hours for certain percentages of final flow.

There are many cases where a small initial distortion in an engineering member is of no consequence and can be permitted, provided such distortion can be held within satisfactory bounds. These curves permit one to assign a working stress which must not be exceeded. Again, if for certain purposes indefinite life is unnecessary, expense can be saved by proportioning for stress which can be safely borne for the requisite time. Finally, the proportional limit determined to within the one-millionth of an inch affords a basis for the designs of structures to last indefinitely.

In all cases the low loads that alone can be borne at high temperatures make the design of parts to be used at such temperatures a trying matter. The proportional limit being low, heavy sections are necessary, while the inclusion of any ordinary factor of safety is likely to result in a monstrosity or an impossible design.

As at high temperature the proportional limit is generally dropping rapidly with increasing temperature, making any overrun in temperature extra hazardous when the material is in use, one is thus between Scylla and Charybdis. He must choose to be content with a moderate factor of safety and put the responsibility for keeping to the operating temperature limits and pressures upon him who specifies them in his order. Hence it behooves users of high temperature apparatus not to go beyond their specifications in the matter of heat or pressure, even though the temptation may be strong. In only one way can this be done with a reasonable measure of safety; by taking into account the extent of the slow flow preceding the final rapid flow leading to rupture.

If his specified conditions be not much exceeded it is probably fairly safe to count that a limit stretch of 8 per cent can be allowed before the danger zone is entered. The point is not yet settled, however, and even 5 per cent would be considered high by some.

In every case where the conditions will permit, it is far better practice to insulate or cool a part than to exact the limit of possible

performance. Thus in a catalytic chamber a lining can often be provided, spaced from the chamber wall, and a gas involved in the reaction introduced between them, so preliminarily warming the gas while cooling the stress-bearing walls.

Of course, when using temperatures producing oxidation allowance must be made in any design for the reduction of the section through this cause.

DESIGN

In designing vessels for high pressures, there should be kept in mind the difficulties confronting the manufacturer, and the form of the vessel made as simple as possible. Small vessels, say up to about 20 inches inside diameter, can generally have one end left solid, but as the production of solid-end cylinders means boring out a solid block, this method becomes wasteful and therefore expensive for much larger diameters.

Hollow forgings are generally finished in V-dies upon a mandrel. Naturally, the equipment of a steel plant cannot include mandrels of every size, and when the proposed diameters are large, say over about 35 inches, it is well to consult the manufacturer before definitely deciding upon the sizes, thereby heavy expense for equipment or additional machine work may be avoided.

The largest mandrel in use in this country today is 72 inches in diameter. On it, lengths up to about 45 feet can be forged. Above that diameter, hollow forgings are today made by drawing a thick-walled cylinder to the desired length and then expanding it to the required diameter. This process is less accurate in its control of sizes and very much more circumscribed in the lengths it can produce, than is the method of drawing in the V-dies. The length of the forging is practically limited to the width of the press anvil block or at most but very little in addition. About 12 feet is the usual maximum length of such expanded forgings.

All enlargements of the main diameter of a cylinder are likely to add to its cost, as possibly requiring the use of ingots larger in diameter than would otherwise be necessary.

It is generally not economical to forge the wall of any vessel thinner than about 2½ inches, and this economical thickness increases with the internal diameter. At 60 inches, the minimum forged economical wall thickness is about 5½ inches.

When circumstances permit, it is frequently advisable partially to close-in the open end of high pressure cylinders to reduce the diameter of the head and its gasket, thus reducing the number and size of the retaining bolts.

MATERIALS

As has been mentioned before, reliable curves showing the physical properties at various temperatures of simple steel of several different carbons and of a number of alloyed steels and alloys have been published, from which one can often select a material which will answer for his particular use. It should always be borne in mind, however, that two pieces of steel of approximately the same composition may have physical properties differing quite widely, and that the curves published are correct for the particular sample tested. Differences in composition, differences in the balance of alloying elements, differences in the size of the forgings, differences in the heat treatment applied, differences in the methods of manufacture employed by different plants, differences in the accuracy of measurement, all will affect the physical properties shown by two different steels on test. It is therefore believed that it would probably be a safe general rule to follow that not more than 80 per cent of the published stresses, regarded reliable, should be considered as figures that could be generally used in practice.

MANUFACTURE OF PRESSURE VESSELS

Casting and Forging—To aid in the practical application of such information as is available to engineers on the properties of steel at high temperatures, let me describe briefly the methods followed in the production of pressure vessels and give some of the points that should be kept in mind in designing them.

Except in the case of certain special alloys, the manufacture of weldless high pressure vessels proceeds along essentially the same lines. An ingot is cast of open-hearth or electric furnace steel of suitable composition and of a size which has been as great as 108 inches in diameter and a weight of 470,000 pounds.

Depending upon circumstances, the ingot is cooled, bored, and freed from the top scrap while cold; or it is reheated, cut to weight and punched or trephined, while hot. In almost all cases, after

Large Petroleum Cracking Pressure Vessel Made from an Ingot 108 Inches in Diameter and Weighing 470,000 Pounds.

reheating, the hollow billet is expanded in diameter by being forged upon a mandrel supported at each end. When the hole is sufficiently large, the billet is reheated and forging proceeds on a mandrel between bottom V and top plain dies.

If the cylinder is to have integral heads, the exterior of the forging at the ends, which have purposely been left large in diameter, is contoured in a lathe to give the thickness in the finished heads which is desired. The ends are then reheated and closed-in, the metal in the walls partly drawing out and partly increasing in thickness.

Treatment and Testing—After the forge work has been completed, the cylinder is annealed above its critical temperature to relieve stresses and to refine the grain. Depending upon circumstances and the results desired, the piece may either be slow-cooled in the furnace, or be reheated and normalized by cooling in the air, or be quenched in oil or water and tempered at a temperature below the Ac_1 point. After heat treatment, the forging is usually tested for physical properties, although sometimes, on account of the shape, testing must be deferred until later.

Machining and Proof Testing—If the cylinder is to be machined on the interior and is to have integral heads, it will generally be necessary to do the boring before closing-in the ends. Pressure cylinders may or may not be machined on either the inside or the outside, depending largely upon their use. They always require some arrangement for sealing the ends, and here machining is always necessary for the fitting of the desired obturading device.

When the cylinder is completely finished and assembled it is customary to give it a hydrostatic, or in some cases a pneumatic, pressure test designed to develop any weakness in the structure or any lack of tightness. The pressure used in such tests varies from one which will produce a stress of about ⅔ of the proportional limit of the metal, to five times the desired working pressure in the case of steam boilers.

TYPES OF FAILURE OF STEEL

By Robert Job

Abstract

Steel fails in many different ways, depending upon the character of the metal and the conditions of service, and in order to avoid failures and obtain the best possible life, it is important to find out just why each failure occurs. Steps can then be taken to make such changes as are found necessary and radical improvement in service is often possible.

A number of illustrations are given in the paper to show a few types of failure, and to indicate the manner in which the information is utilized to put a stop to repetitions.

THE rapid development of industrial life within recent years has introduced countless new uses for steel and other metals. It has also made such radical changes in the conditions of service that the steel of yesterday, which reasonably well met the requirements and gave a good account of itself, today under more exacting conditions now prevailing is often ill adapted to meet the demands to which it is subjected.

To cite a few examples, the steel staybolt today is very different in its properties from the staybolt formerly used, and the same statement properly may be made regarding firebox steel, or the steel for axles, crank pins, piston rods, and other forgings, and even the steel used in the construction of bridges and buildings is becoming stronger and tougher and less susceptible to "fatigue" as a result of changes which have been made or are taking place in composition and properties.

Failures of steel have occurred in the past, and unfortunately will continue in the future in spite of increased knowledge regarding its manufacture and treatment. Slips take place in mill practice or in the shops, resulting in a deficiency in strength or ductility or in the ability to endure under stress, and in consequence ma-

terial sometimes goes into service predestined to failure before its life work is begun.

Under such conditions it is a matter of great practical importance to determine definitely the real cause of any given failure in
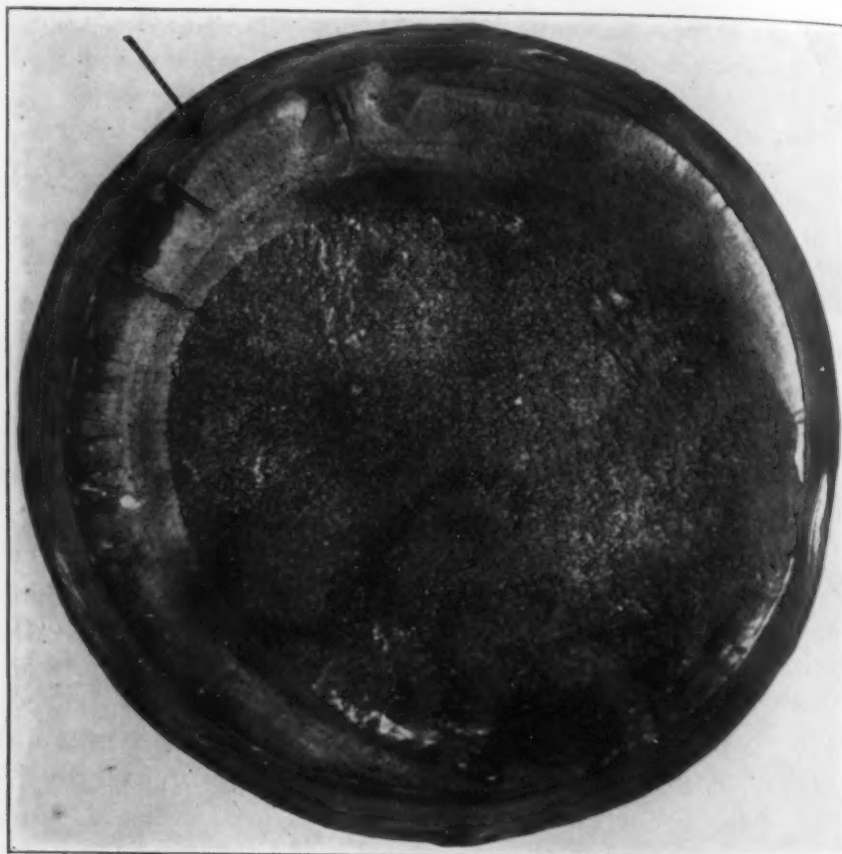
Fig. 1—Failed 9½-inch Axle. Fracture in Detail, Due to Sharp Fillet

order that the correct remedy may be prescribed and steps taken to prevent or to forestall repetitions.

In some cases the cause of the failure is indicated clearly by the appearance, while in others a detailed investigation may be necessary before the underlying cause is brought to light. Some types of failure are seen frequently, others rarely, but all are interesting and each one when the details of it are thought out to a logical conclusion suggests changes which should be made and precautions taken in the mill or in the shop in order to safeguard the service and avoid future loss.

Failures are seen in many different guises, each with its own

characteristics, and it may perhaps be of interest to show and to describe a few instances to illustrate our meaning.

The photograph Fig. 1 shows the fractured surface of a locomotive trailer axle, 9½ inches in diameter. The failure began just outside of the wheel fit where the diameter of the axle increased from 8½ to 9½ inches. A hair crack first started, gradually extending around the axle and then penetrating inward toward the center as shown in the photograph. After a time the crack had progressed so far that the remaining metal was insufficient to support the load, the axle broke, throwing off the wheel and causing an engine failure, fortunately without loss of life.

Analysis and physical tests showed that the steel was of good standard quality and that the heat treatment had been correct. The whole trouble in this case was due to carelessness in machining. Instead of making a fillet with a good wide angle and gradual slope, the journal was finished with a narrow angle at the point where the diameter increased, thus centering the stresses and causing ultimate failure. A condition of this kind gives unmistakable evidence of defective shop practice and perfunctory inspection of the finished axle at the time when it was placed in service.

Fig. 2 shows a totally different type of failure. The photograph shows a knuckle pin split in half longitudinally. In this case as in the preceding, the composition did not indicate the cause of failure though the steel was somewhat harder than usual. Examination of the broken surface showed a series of longitudinal lines, and their form gave clear proof that there had been severe torsional stress which had resulted in actually splitting through the middle a steel bar about four inches in diameter and six inches long.

This condition may have occurred in one of two ways. The pin may have been taken from the cold when at a low temperature and placed directly in a hot furnace without preliminary warming or gradual and reasonable increase of temperature. On the other hand it may have been thrown, while at a high temperature, into a cold quenching bath and allowed to lie upon the bottom of the tank while cooling. Under such conditions the top and the bottom of the forging would be cooled unequally, introducing severe torsional stresses which might easily result in the rending of the metal, and we have known of instances in which heavy steel forgings when treated or rather mistreated in this manner have "let go," twisted apart from end to end.

These details of shop practice are so well known that failure of this type should never occur, but the appearance of the fractured pin is proof of the need of instruction of the men, combined with careful supervision of the process.

In Fig. 3 we see a reclaimed helical car spring. This spring split into several pieces when being compressed in the testing ma-
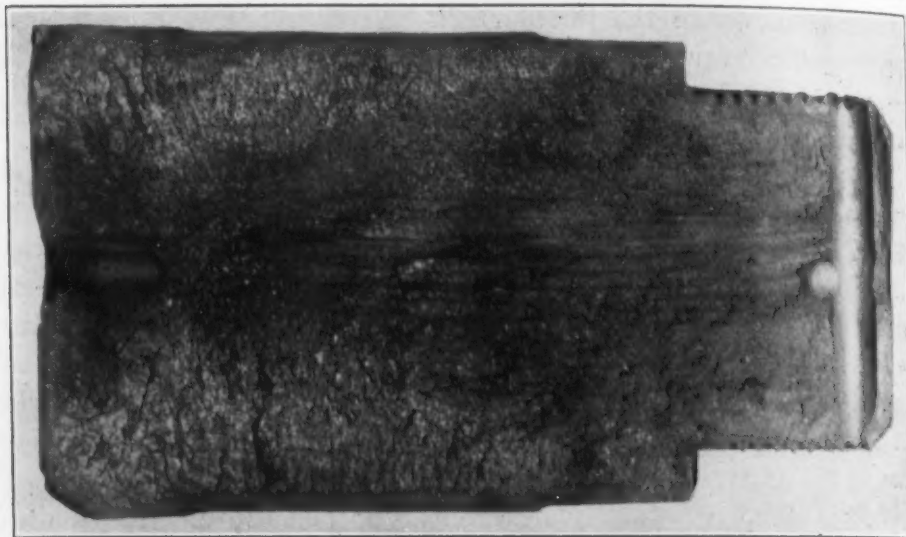
Fig. 2—Failed Knuckle Pin.

chine after the "reclaiming process." In the photograph we see the line of the longitudinal crack. One of these extended along both the outside and the inside portion of the bar.

The appearance when looking upon the fractured end of the same helical spring is shown in Fig. 4. The lines of the cracks are clearly seen and it was found that the steel was coarsely granular. Also a small internal transverse fissure is shown at the lower longitudinal crack with its characteristic nucleus where the metal first parted under tension.

These conditions indicated that in the reclaiming process the hardened spring steel when cold had been placed directly in a hot furnace without the proper gradual increase of temperature which was particularly necessary in treatment of hardened spring steel. This incorrect procedure caused the longitudinal cracks. The coarse-grained condition of the steel showed that the furnace temperature was much beyond the critical point of the steel. The failure was

Fissure
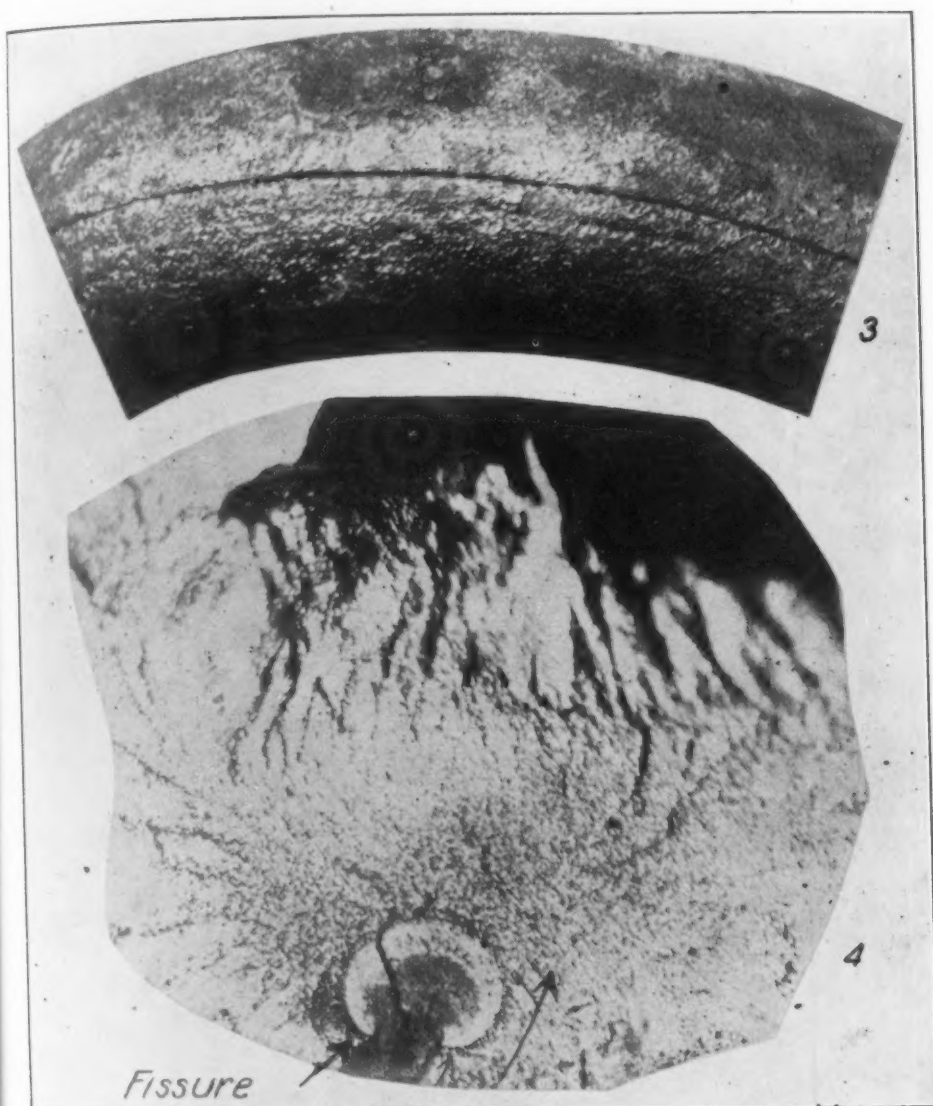
Fig. 3—Failed Helical Spring.   Fig. 4—Failed Helical Spring.   Fractured End.

thus a result of disregard at the reclaiming plant of two elementary principles of heat treatment.

Owing to the general use of high speed steel, mechanics became accustomed to taking heavy cuts from metal, with the resultant rough finish. The men do not always realize that on a shaft or axle where a smaller diameter merges into a larger one a rough finish may easily become a vital defect, as is the case with too sharp a fillet. Fig. 5 shows the condition of the fractured end of a 6-
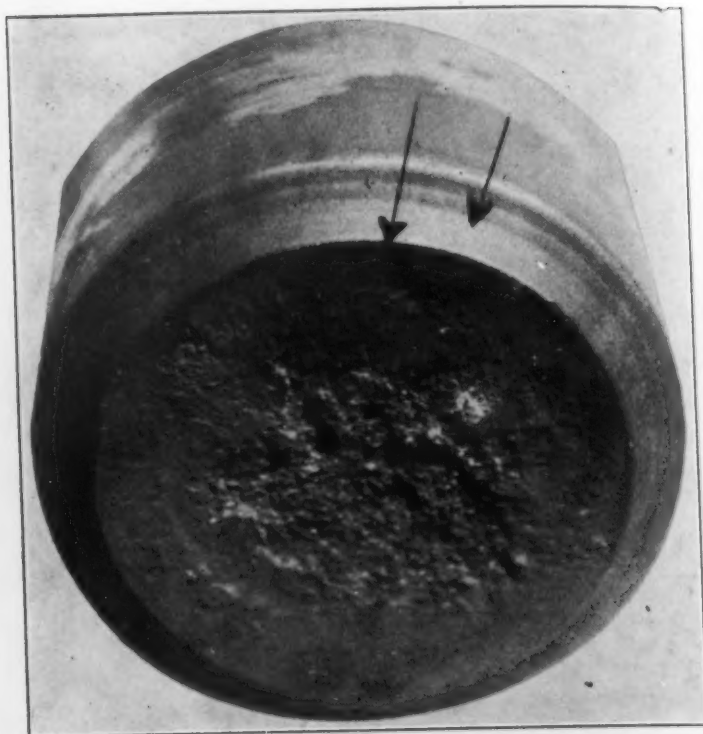
Fig. 5—Broken 6-inch Axle.　Rough Tooling.
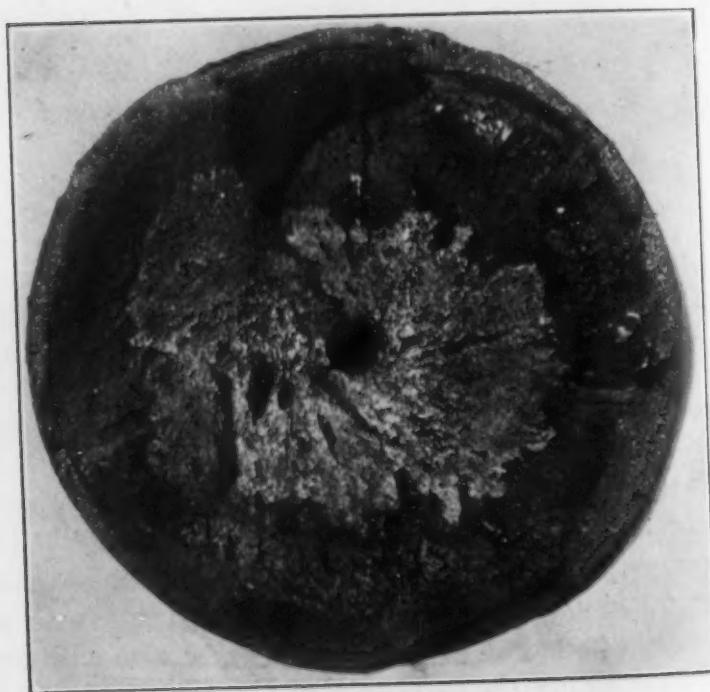
Fig. 6.—Quenching Crack.
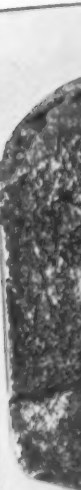
inch axle with ridges due to rough tooling at and near the fillet, just the location where every care should be taken to leave a smooth finish. Here again we have an instance where the failure of an axle of good standard quality is attributable to a little too much

Fig. 7—Failed Steel Rail.   Nick in Head, Due to Defective Wheel.

hurry in the finishing operation, coupled perhaps with lack of knowledge as to the importance of smoothness of finish of metal subjected to special stresses.

The photograph Fig. 6 illustrates the appearance of a pin which had been case hardened and then quenched in water. In this instance the proportion of carbon was too high, the shock produced by the drastic cooling was too great, and the metal tore apart with the spiral appearance to be expected in a fracture of this type.

Let us now turn to steel rails. In Fig. 7 we see the character-istic fracture which was caused by a nick about one-quarter inch

deep cut into the running surface of the head of a rail by a shelled
tire or defective wheel. Failures of this type are especially apt to
occur during cold weather or on a frosty night when the rail is
under greater tension than usual. The fracture begins at the nick
in the head and quickly tears its way through the rest of the sec-
tion. One bad wheel is likely to work havoc in the course of a few
hours since it makes its mark upon a rail head with each revolu-
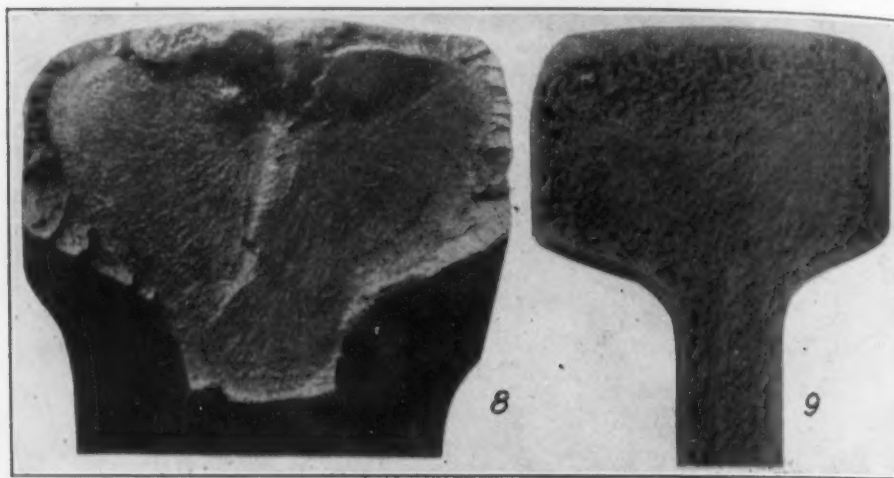
Fig. 8—Internal Transverse Fissure. Austrian Rail—Mild Steel. Fig. 9—Unsound
Steel. Austrian Rail.

tion of the wheel. In one instance which we have in mind, seventy-
six rails were broken by a single defective wheel in a single night.
In that case the mark or cut was characteristic and unmistakable.
Luckily this wheel, on an engine tender, soon was detected by the
noise of the blows and was removed from service.

The type of fracture known as an internal transverse fissure,
in a rail of mild steel (about 0.25 per cent carbon) is shown in
Fig. 8. This particular instance occurred in Austria twenty-five or
thirty years ago and was investigated there by Anton von Dormus.
It was found that these defects gradually developed in track under
traffic but it was reported by Dormus that they occurred only in
rails of unsound steel, as shown in one of his illustrations (Fig. 9),
the metal being radically unsound and incapable of normal serv-
ice even under the light loads then prevalent.

Another illustration, (Fig. 10), shows the broken end of a
car axle, a type known as a "burn-off." The metal at the fractured
surface has a twisted, spiral appearance and the fibers of the metal
are pulled upward showing that they parted under tension. The

face of the metal is dark and discolored and frequently covered with magnetic scale.

These conditions indicate at a glance that the axle has run hot, a "hot-box." The journal due to lack of lubrication, dirt and grit or other cause started to heat, becoming hotter and hotter

Fig. 10—Failed Axle—"Burn-Off."

until the axle finally became nearly red hot and the wheel then twisted off from the softened metal, causing a wreck. A hot-box generally is detected long before the danger point is reached, but in this instance through accident or neglect no warning was given until the cars piled up in the ditch.

Subsequently it was claimed by the men that a sudden failure occurred without warning due to a defect in the steel. The appearance of the fractured surface, however, with its tell-tale spiral oxidized surface, proved the real cause of the failure.

The few examples which we have given will serve to show clearly the saving in time, money and lives which should follow as a result of the careful scrutiny and investigation of failed materials.

In conclusion I wish to acknowledge the assistance of Charles H. Lester in the preparation of the photographs.

STEELS FOR CASE NITRIFICATION

By A. B. Kinzel

Abstract

This paper includes a study of the effect of various alloying elements on the case resulting from low temperature nitrification and shows particularly the extreme hardness and general desirability of the case obtained with vanadium steel, when a minimum of 0.4 per cent vanadium exists in solid solution. The matter of treating the surface of plain carbon steels with aluminum or vanadium and then nitrifying has also been investigated and satisfactory cases have been obtained in this way.

The properties of a steel containing 0.4 per cent vanadium in solid solution make such a steel particularly suited to industrial application.

THIS subject was first successfully investigated by Fry who developed the aluminum-bearing steels for nitrification. With these steels, a treatment in ammonia at 930 degrees Fahr. (500 degrees Cent.) or thereabouts for a sufficient length of time, results in a hard nitride case which is adaptable for service under a great many conditions. The advantages of the case and of the process are exceptional surface hardness and bright finish together with freedom from distortion of the piece.

Object of the Paper

There has long been a discussion among metallurgists regarding the effect of aluminum on steel. Abnormality in aluminum steels has been cited and there is a prevalent belief that aluminum additions lower the quality. A discussion of this matter is not pertinent to this paper. It is sufficient to note that due to the above objections, the author started out to develop another steel for nitrification. Two methods were considered; to have an aluminum alloy surface on the steel without having aluminum in the core, and to find another alloy which would produce a similar

type of case on nitrifying and which was free from the above mentioned objections.

PROCEDURE OF STUDY

Calorization-Nitrification

In order to obtain aluminum on the surface, the usual calorizing procedure was followed using ordinary low carbon steel. This was carried out at a temperature of 1020 degrees Fahr. (550 degrees Cent.). It was found on nitrifying the calorized piece, that a definite case resulted but that its hardness was very low. This was believed to be due to too much aluminum. To reduce the aluminum concentration at the surface, a calorized piece was soaked at 1830 degrees Fahr. (1000 degrees Cent.) for two hours, cleaned and nitrided. The result of this nitrification was a very hard, satisfactory case. Of course the high temperature soak defeats one of the aims of the process, namely, to avoid deformation and scaling. Accordingly, experiments were performed to obtain the proper concentration of aluminum on the surface directly. It was found that calorizing at 1020 degrees Fahr. (550 degrees Cent.) for one-half to two hours gave the desired concentration. This was repeated with chromium-bearing steel and the case obtained was even harder.

Calorizing in ammonia instead of in hydrogen was tried and found to be successful. However, the process of calorization and nitrification cannot be carried out without first removing the sample from the aluminum, as otherwise too much aluminum is picked up and a soft case results. To find out whether any general embrittling effect occurred, a specimen of ordinary low carbon steel was treated as indicated and showed a value of 80 Izod bend before calorization and nitrification and 78 afterwards, the difference being negligible.

This method while effective, seemed to the writer to have certain disadvantages from a manufacturing standpoint. These disadvantages include some uncertainty of calorization concentration and the general nuisance of a double process. Accordingly, the second of the previously mentioned methods, the search for a new alloy, was undertaken.

NITRIDE CASE HARDENING ALLOYS

The nitride case hardening effect of chromium, silicon and

manganese has been previously shown by Fry and others. It has been shown that small percentages of these elements increase the hardness of the nitride case somewhat but not nearly as much as does aluminum. In the present investigation the author has found that additions of tungsten and titanium up to 1 per cent result in no appreciable hardening under the conditions used. The case obtained by zirconium showed a very peculiar effect. Up to a certain critical amount the hardness of the case increased and beyond that critical amount no case at all appeared. This amount is too critical to control. A vanadium addition however showed promise and a more detailed study of the effect of vanadium on the resulting case was made.

Vanadium as a Nitride Case Alloy

Vanadium steels with varying vanadium and carbon contents were prepared and nitrided in ammonia at 950 degrees Fahr. (510 degrees Cent.) for 15 hours. It was found that with carbon below 0.1 per cent and vanadium 0.5 per cent or greater, a case with a hardness corresponding to Rockwell "C" 67 or more was obtained. With 0.40 per cent vanadium the case corresponded to a hardness of about 60 Rockwell and with 0.20 per cent vanadium the hardness ran about 35 Rockwell, which is negligible. With a steel containing 0.30 per cent carbon and 0.50 per cent vanadium, a hardness of 64 Rockwell was obtained. The accompanying data (Table I) shows the composition of the various steels nitrided and the estimated hardness of the case obtained.

From this table it is apparent that the hardness increases with increasing vanadium content, the carbon being constant. It is also apparent that the hardness decreases with increasing carbon content, the vanadium content being constant. From a study of the carbon-vanadium proportions it appears that 0.4 per cent vanadium in solid solution is necessary to obtain a maximum hardness provided no other ferro alloys of the nitride case hardening type are present. The effect of chromium, manganese and silicon is to increase the effectiveness of small quantities of vanadium. Thus, the heat which contained 0.3 per cent chromium, 1 per cent silicon, 1 per cent manganese, 0.30 per cent carbon and only 0.30 per cent vanadium gave maximum hardness despite the low vanadium and the low vanadium and carbon ratio.

The matter of time of nitriding and depth of case was also

Table I
Composition of the Various Steels Nitrified

Cr	Mn	Analysis Per Cent Si	C	V	Brinell	Rockwell "C"
					Estimated Hardness of Nitride Case	
			0.06	0.2	300	35
			0.06	0.4	650	60
			0.06	0.5	900	67*
			0.06	1.00	900	67*
			0.06	2.00	900	67*
			0.3	0.5	700	63
			0.6	0.5	500	50
			1.00	0.5	400	45
			1.00	15.0	900	67*
1.00	0.6		0.3	0.4	900	67*
1.00			0.3	0.1	400	45
0.3	1.00	1.00	0.3	0.3	900	67*
(decarburized)			1.00	0.5	900	67*
			1.00	(decarburized) and (vanadiumized)	900	67*

*Maximum hardness. The hardness number is probably more than given.

investigated. An 0.50 per cent vanadium low carbon steel was used for the tests at 950 degrees Fahr. (510 degrees Cent.) in ammonia, the following results being obtained:—

Time	Depth of Case
72 hours	0.5 millimeters
22 hours	0.4 millimeters
15 hours	0.3 millimeters
6 hours	0.2 millimeters
2 hours	less than 0.1 millimeters

DECARBURIZATION AND VANADIUM CASING

Carbon is seen to reduce the effectiveness of the vanadium, probably by cutting down the amount of the latter in solid solution. It is necessary to use greater amounts of vanadium in steels with increasing carbon contents. However, only the carbon on the surface is objectionable, and the author has succeeded in removing the carbon and nitrifying in one heating thus permitting the use of a low-vanadium high-carbon material, should this be desired. This experiment was carried out as follows:—

The material used was a 0.5 per cent vanadium, 1 per cent

carbon steel, which on nitriding would ordinarily show a case hardness well below the usual maximum. The material was heated in a stream of hydrogen at 1290 degrees Fahr. (700 degrees Cent.) for 130 minutes. The temperature was then dropped to 950 degrees Fahr. (510 degrees Cent.) and ammonia substituted for the hydrogen. This was continued for 15 hours and the resulting piece of steel showed a hard nitride case of 67 or better Rockwell "C" indicating that the hydrogen had effectively removed the excess surface carbon but not the surface vanadium. This decarburization was checked by microscopic examination.

The casing with vanadium itself is also of interest. In this connection the following experiment was performed:—A piece of plain carbon tool steel (1 per cent carbon) was decarburized in a stream of hydrogen at 1290 degrees Fahr. (700 degrees Cent.) for 130 minutes in intimate contact with finely powdered ferro-vanadium. Nitrogen was substituted for the hydrogen and the material held at 1690 degrees Fahr. (900 degrees Cent.) for two hours. The temperature was then reduced to 950 degrees Fahr. (510 degrees Cent.) and ammonia substituted for nitrogen. This was run for 15 hours more. This sample developed a nitride case with a hardness greater than 67 Rockwell, indicating that the steel had been decarburized, vanadium cased and nitrided. A separate sample was run at 1690 degrees Fahr. (900 degrees Cent.) in nitrogen for two hours, the sample being in contact with powdered ferrovanadium. Analysis showed that an appreciable amount of the vanadium had alloyed with the specimen.

Hardness Measurement

A word might be said here as to the measurement of the hardness of the nitride cases. The usual methods are ineffective because of the very thin cases obtained. The author understands that the Herbert pendulum tester is satisfactory but he has not used it in this study. It was found practicable to measure the hardness of the case with a Rockwell ball, the dial reading then corresponding to the combined deformation of the ball and the case. In addition, microcharacter hardness measurements were made to check the values found by the Rockwell hardness method and although accurate hardness numbers are not obtained, the general order of hardness is sufficiently well defined in this way.

In Table I the hardness so obtained has been converted to the usual Rockwell "C" and Brinell scale to facilitate comparison.

Conclusions

Experiments show conclusively that the presence of vanadium in proportions such that a minimum amount, probably 0.4 per cent remains in solid solution in the steel, causes the case which is formed on low temperature nitrification to be extremely hard and desirable in every way. The hardness is equivalent to that obtained on using aluminum in the steel. These properties coupled with the excellent qualities resulting from the use of vanadium make the vanadium steels highly desirable for the case nitrification work.

Acknowledgment

The author wishes to express his appreciation of the cooperation of his colleagues at the Union Carbide and Carbon Research Laboratories, particularly of the work done by John J. Egan, in connection with this investigation.

DISCUSSION

Written Discussion: By P. C. Osterman, American Gas Furnace Co., Elizabeth, N. J.

In our numerous tests of a great variety of steels, comprising ordinary steels and also steels especially made for nitrogenizing, we have found the most satisfactory steel to be a molybdenum-aluminum steel. For certain commercial parts even as short a time as eight hours gave a sufficient depth of case.

The ordinary carbon steels when nitrogenized do not show anywhere near the increase in hardness that is secured with steels especially made for the purpose; however, nitrogenizing will undoubtedly often prove advantageous on ordinary steels from the standpoint of corrosion-resistance which nitrogenizing does give in a high degree.

As in other heat treatments, the removal of mill scale is important. If nitrogenizing is carried out on parts covered with mill scale, a soft friable shell is produced which is easily removable; however, under this shell is found a hard surface.

Another instance of nitrogenizing which I might mention is the nitrogenizing of cast iron parts for water pumps. A number of parts so treated have proved entirely satisfactory in field tests, and it is now proposed to regularly so treat these parts.

Written Discussion: By H. A. DeFries, Ludlum Steel Co., Watervliet, N. Y.

In our work at the Ludlum Steel Company we have nitrided numerous

steels, besides the so-called Nitralloy steels which comprise all those carrying aluminum. The manufacture of these aluminum-bearing steels has been perfected and I may say that they are made today successfully not only in the electric furnace but also in the open-hearth.

We were never able to obtain the same degree of hardness on any steel without aluminum as we secured with Nitralloy steels. This includes vanadium steels. I may mention also that all steels without aluminum content are very erratic during nitriding, whereas the aluminum-bearing steels give consistent and uniform results.

We have discarded the Rockwell hardness test completely for measuring the hardness of nitrided cases, as the diamond point either penetrates the case or fractures. Mr. Kinzel gives for maximum hardness of nitrided vanadium steels 67 Rockwell C which he transfers into 900 Brinell hardness number. Our experience has been that 67 Rockwell C in Brinell numbers is nearer 700 than 900. We are using today the Herbert pendulum only, and this instrument has given us a maximum hardness of 730 Brinell for nitrided vanadium steels, against a minimum of 900 and a maximum of 1100 Brinell on the Nitralloy steels.

Nitralloy steels in the beginning showed some defects, especially an embrittlement of case and core after nitriding. The first steels produced, for instance, had an impact value of 15 Izod before nitriding and only 5 Izod after nitriding. These defects are now entirely eliminated by a change in analysis. Nickel was eliminated to a great extent and molybdenum was added in small quantities. The series as marketed today can be classified as follows: aluminum-molybdenum steels and aluminum-chromium-molybdenum steels. Both grades are made with varying carbon content. These steels especially the aluminum-chromium-molybdenum series are free from embrittlement during nitriding. The impact value before being 15 Izod and 14.7 after.

This improvement has also resulted in obtaining a decidedly more ductile case, without detracting much from the hardness obtained with the previous steels. Another improvement has been the possibility of obtaining satisfactory nitride cases in a much shorter period, than was found necessary at the beginning.

Since it has been found practical to incorporate the required alloys in the steel itself, I do not see any advantage in trying to infuse them into the surface by pure hydrogen, or the hydrogen from the disassociation of the ammonia. Such a procedure will require at least two operations and unnecessarily complicates matters. Again there is the uncertainty whether the infusion has been carried on uniformly over the whole surface. Uniformity is essential to obtain a case free from soft spots.

In regard to the nitriding proper, nothing new is disclosed in Mr. Kinzel's paper,: as all his work for this step of the process has been carried out below the peritectic point, or well within the limits covered by the Fry patent.

INCLUSIONS IN IRON

*A Photomicrographic Study**

By C. R. Wohrman

CHAPTER III

Sulphide Inclusions

1. *Brief Review of Earlier Work*

THE first inclusions that were recognized in steel, and described in the literature were sulphides.

The detrimental influence of sulphur on the rolling properties of steels and the beneficial effect of manganese in correcting this were early recognized by steel makers and aroused early the curiosity of metallurgists (1, 2, 3). Osmond and Werth (4) were the first to show—in 1885—that the sulphur in steels containing manganese existed as the sulphide of manganese. They arrived at this conclusion from a chemical study of steel.

Microscopical study of failures of steel parts by Andrews[20] appears to have led to the first discovery of sulphide inclusions. The microscope then was applied to a study of the form in which these inclusions occur, by Arnold. He describes (11, 13), iron sulphide inclusions as of "pale brown color", existing, first, as "globules" or "ovoids", second, "as thin laminae of an irregular oval shape" and third, "as cell walls presenting in section a mesh-like appearance"; he classes the second form as "dangerous" and the third as "most dangerous". Manganese sulphide, according to Arnold, appears as "dove-colored globules or ovals, sometimes as oval laminae, but . . . . very rarely as meshes, manganese seeming to almost entirely prevent the formation of cell walls of sulphide."

Le Chatelier, in 1902, in a brilliant paper on the "Sulphide of Iron" (16) broadly confirmed the observations of Arnold. He further noted the infusibility of MnS and the incompleteness of

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[20]"Microscopic Examination of Flaws Inducing Fractures in Steel." 1896, p. 20.

sulphur removal by manganese; described for the first time the sulphide-oxide eutectic and explained the difference in the distribution of FeS and MnS in the metal.

Some of Le Chatelier's observations were, in turn, confirmed by Arnold and Waterhouse (17).

The next important contribution to the knowledge of sulphide inclusions was furnished by Treitschke and Tammann (23) who worked out the first equilibrium diagram of the system Fe-FeS. This diagram appears to be faulty in many important details, and has been misquoted and misinterpreted by later writers.

E. F. Law (25), in 1907, pointed out that the sulphide occurring in steels "varies very much in color and composition" and correctly surmised that this was ascribable to "manganese sulphide dissolving a certain amount of iron sulphide". Law disputes, however, Le Chatelier's statement about the high melting point of MnS. He states: "the author . . . had no difficulty in melting manganese sulphide in an ordinary coke-fired assay furnace, which was quite incapable of melting mild steel."

Some years later (1911) D. M. Levy (33) found that "pure manganese sulphide requires a temperature of upwards of 2640 degrees Fahr. (1450 degrees Cent.) in order to cause fusion." He also found that manganese and iron sulphides were soluble in all proportions when molten, and partially soluble (MnS holding a maximum of 50 per cent FeS in solid solution) when solid. He distinguished between three types of manganese sulphide:

"(a) dark colored, more free from FeS and most infusible;

(b) paler varieties, containing up to 50 per cent FeS in solid solution, more fusible;

(c) composite sulphides consisting of MnS-FeS solid solution together with FeS itself."

The latter findings of Levy were, in substance, confirmed by the work of G. Röhl (37) which marks another important advance in our knowledge of sulphide inclusions. Röhl worked out the first FeS-MnS equilibrium diagram; he established the existence of solid solutions between FeS and MnS, and, as he thought, the existence of a compound $Fe_3Mn_2S_5$. He found the melting point of MnS to be in the neighborhood of 2950 degrees Fahr. (1620 degrees Cent.), verifying thus the original contention about the relative infusibility of MnS of Le Chatelier.

A. L. Feild in discussion (46) disapproves of Röhl's ideas, stating: "It is not true that a solid solution of the two sulphides separates from iron on solidification." He finds that Röhl's FeS-MnS system "fails to check the data of Levy", also that "conclusions based on these erroneous results are employed in his later deductions regarding occurrence of sulphides in the very small melts employed."

A. McCance (41), referring to the evidence advanced by the work of Arnold and Bolsover (38), also disputes the correctness of Röhl's contentions in regard to the existence of solid solutions of MnS-FeS. Examining the "evidence" he finds that "no real support" for the conclusions of Röhl can be found. The reaction

$$FeS + Mn = MnS + Fe$$

is not a balanced one, according to McCance, and accordingly "sulphide inclusions in steel . . . may be MnS, but they are not likely to contain any FeS even in a state of solid solution."

The existence of FeS-MnS solid solutions was, however, advocated again by Zen'ichi Shibata (48), who, recently, worked out a new FeS-MnS equilibrium diagram which differs from that of Röhl in many details. Shibata checks the melting point of MnS as determined by Röhl, giving it as 2930 degrees Fahr. (1610 ± 3 degrees Cent.)

The contention of McCance about the irreversibility of the reaction

$$FeS + Mn = MnS + Fe$$

was justified, acording to A. L. Feild in discussion (47), since "by far the greater weight of evidence inclines toward two conclusions:

(1) That the reaction proceeded toward the right to practical completion in the ideal case of the three-component system Fe-Mn-S with iron in large excess; and

(2) That the presence of oxygen as a fourth component was responsible for that apparent reversibility which occurs to so marked a degree in ordinary steel practice."

A. L. Feild finds further that the paper of Herty and True (47) in which the latter attempt to prove the reversibility of the reaction

"brings forward the first reliable evidence of a direct sort to support the view that the reaction is reversible." He fails to see however, that Herty and True were dealing with oxy-sulphides,[21] as shown by their Fig. 2, for example, and that therefore the presence of oxygen, again, can be blamed for the "apparent reversibility."

It should, perhaps, be mentioned, that Arnold and Bolsover (38), in 1914, recorded "the probable existence in fluid commercial steels of a eutectic of ferrite and sulphide of manganese which has a very high freezing point." This statement has been largely ignored by later investigators.

Individual important papers bearing directly on some of the questions that presented themselves in the course of the author's study will be discussed in greater detail in the appropriate connections later.

From the above brief review of outstanding papers on sulphide inclusions it is evident that agreement is lacking. In particular, the existence of solid solutions between MnS and FeS is doubted by many; widely divergent figures have been given for the melting point of MnS; the proof of the reversibility of the reaction $FeS + Mn = MnS + Fe$ is open to criticism. The question of a possible eutectic of ferrite and manganese sulphide must be considered. The exact manner in which the inclusions form has not been adequately explained; least of all the behavior, in the presence of MnS, of FeS which, according to McCance (41) for example, would, upon heating of steels to above 1795 degrees Fahr. (980 degrees Cent.), "redissolve and diffuse into the surrounding steel, and on cooling again . . . would not be redeposited in its original position, but would be deposited in between the crystal grains according to its habit".

In the photomicrographic studies, about to be described, the writer endeavored to pay particular attention to these doubtful points.

3. *Iron Sulphide and Iron*

Five melts of electrolytic iron and pure sulphur were prepared for the study of the iron-iron sulphide relationships. The purity of the melts was checked by analyses which showed the presence of only traces (less than 0.001 per cent) of manganese and of some 0.009 per cent carbon.

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[21]The melts were apparently conducted in air.

Table II

Experimental Melts

Melt	Charge (grams)		To yield* Per Cent		Chemical Analyses of the melt Per Cent		Remarks
S–1	El. Fe S.	51.35 1.00 ——— 52.35	S (Fe S	1.78 4.9)	Mn Trace S (Fe S	1.05 2.89)	Melted in vacuo. Loss of sulphur in this and the other melts is explained by the great tendency of sulphur to escape through the joints between cover and container —probably prior to absorption by iron.
S–2	El. Fe S	28.90 .53 ——— 29.43	S (Fe S	1.8 4.95)	Not analysed; probably like S-1		Solidified slowly (in the course of about 15 min.); cooled slowly.
S–3	El. Fe	135.81 .45 ——— 136.26	S (Fe S	0.33 0.91)	Mn Trace C	0.009	Solidified and cooled fairly rapidly.
					S (Top (Fe S	0.135 0.344)	
					S (Bottom) (Fe S	0.100 0.275)	
S–4	El. Fe S	93.80 0.18 ——— 93.98	S (Fe S	0.19 0.52)	S (Fe S	0.033 0.091)	Loose fitting cover.
S–5	El. Fe Melt S-4	43.6 43.7 ——— 87.3	S (Fe S	0.017 0.046)	S (Fe S	0.016 0.045)	No sulphur escaped, since it was charged as an alloy with iron.
S–6	El. Fe Mn S	80.37 1.10 1.30 ——— 82.77	Mn S (Mn S +Fe S	1.33 1.57 2.11 2.19)	Top fourth Mn S (Mn S +Mn Bottom fourth Mn S (Mn S +Fe S	1.47 0.79 2.15 0.11) 0.58 0.71 0.92 1.02)	Manganese metal charged into the middle of the container with sulphur above and below it.
S–7	El. Fe Mn S	65.00 1.75 1.00 ——— 67.75	Mn S (Mn S +Mn	2.58 1.48 4.02 0.04)	(C Mn. S (Mn S +Mn	0.17) 1.53 0.63 1.71 0.45)	As above.
S–8	El. Fe Mn S	65.40 6.15 .85 ——— 72.40	Mn S (Mn S +Mn	8.5 1.17 3.17 6.50)	Mn S (Mn S +Mn	6.42 0.40 1.10 5.72)	Manganese charged on the bottom of the container and the sulphur on top of it.

*Allowance was made in every case for the escape of sulphur during the melting in vacuo; hence these figures are not representative of what the melts were expected to analyze.
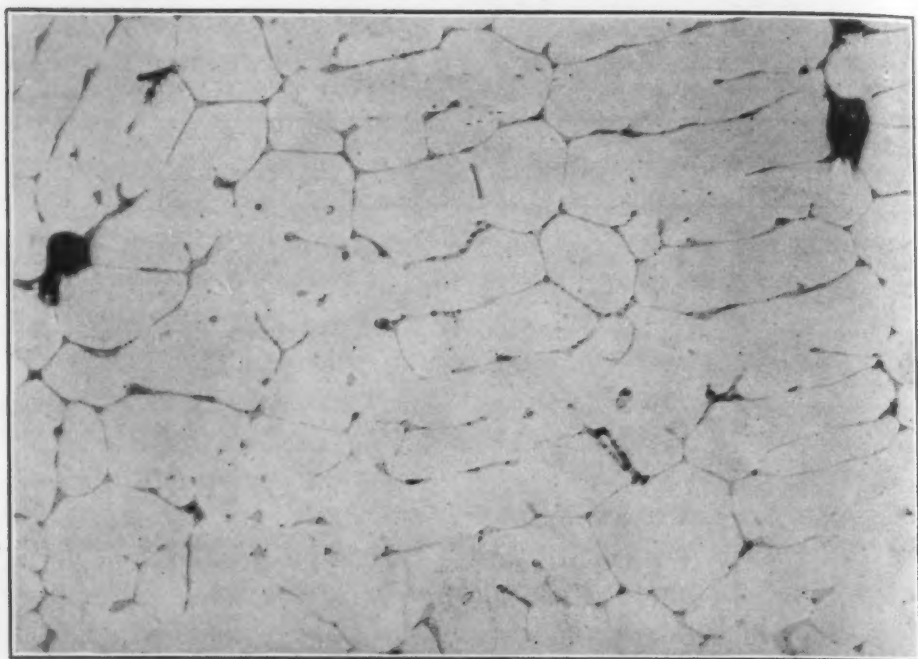
Fig. 43—Photomicrograph of Melt S-1 As Cast Showing the "Cell Wall" or "Enveloping Membrane" Structure of Iron Sulphide. × 100.

Ingots containing from 0.016 per cent sulphur up to 1.05 per cent sulphur were obtained, a range which surely embraces the industrially important cases.

THE HIGH SULPHUR MELTS

(S-1 and S-2)

Description of Inclusions. The high sulphur melt S-1 exhibited the well known "cell-wall" or "enveloping membrane" structure of iron sulphide, illustrated in Fig. 43. The continuity of the metallic mass is seen to be broken up completely,—and this is accomplished, in the present case, by but 1.05 per cent sulphur (2.9 per cent FeS).

Pure iron sulphide is decidedly yellow when contrasted with the brilliant white of the iron; it is, however, a very pale yellow, a "cream" yellow, perhaps. It appears homogeneous throughout, no trace of a eutectic or duplex structure being discernible at the highest magnifications.

High magnifications reveal that not all of the sulphide is concentrated in cell walls; the iron matrix itself is seen to be pep-

pered with tiny rounded sulphide globules. (See Figs. 44 and 45). The larger of these globules seldom measure over 0.0015 millimeters in diameter while the smallest ones that could be identified were of the order of 0.0001 millimeter in diameter (0.1μ). The globules are not always as pronounced as they happen to be in S-1, which, as records revealed, were allowed to solidify and cool rather rapidly. In the melt S-2 of the same composition as S-1, but solidified and cooled slowly, the metallic matrix was found to be much cleaner than in S-1. Small sulphides were not entirely absent, to be sure, but areas essentially free of them could be found with ease (See Fig. 46 and especially Fig. 47, and compare with Figs. 44 and 45, respectively).

Formation of the "Cell-Wall" Structure. Cell-walls are the "habit" of FeS, or FeS "segregates to the grain boundaries forming continuous envelopes around the crystalline grains of the metal" are statements not infrequently met with in the literature. Such statements are highly inaccurate and misleading as will be shown in a later connection (Chapter V); moreover, they do not explain anything.

The facts are simple. Iron sulphide is soluble in molten iron as was shown already by Treitschke and Tammann (23). As the iron solidifies, the sulphide, or at least a considerable proportion of the sulphide, is thrown out of solution and this sulphide being in a molten condition,[22] is forced into the interstices between the iron dendrites where it finally solidifies.

The regularity of the cellular structure is suggestive of such a mechanism, although, failing to see the iron dendrites, it is not always easy for one to correlate the observed sulphide patterns with dendritic fillings. Areas like the ones depicted in the panoramic photomicrograph Fig. 48, show the relationships fairly clearly, yet even here the details exhibited are too pronounced to bring out the general aspects of these relationships. A macrophotograph is called for—and this is furnished in an admirable manner by the well known method of sulphur printing invented by Heyn and Bauer (22) and modified by Baumann.[23] This method has been used by numerous investigators, reproductions of sulphur prints, for example, being given in the papers of Levy (35)

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[22]Melting point of pure FeS is 1193 ± 50 degrees Cent. according to the International Critical Tables.

[23]*Revue de Metallurgie*, III, p. 416.
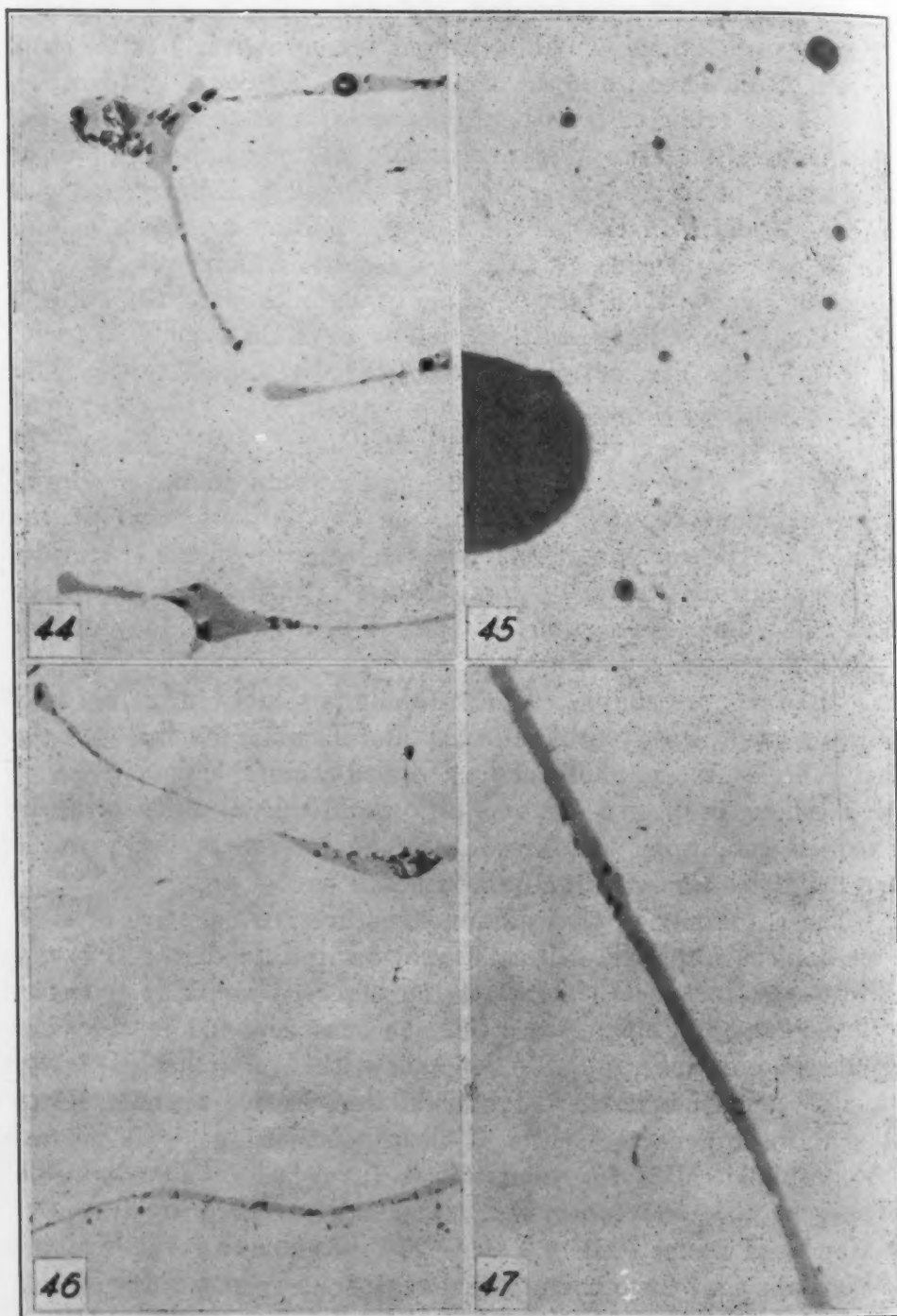
The Matrix of High Sulphur Iron. Fig. 44—Photomicrograph of Melt S-1. Tiny Rounded Sulphide Globules in Iron Matrix. × 500. Fig. 45—Photomicrograph of Melt S-1. Part of Fig. 44. × 2500. Fig. 46—Photomicrograph of Melt S-2. Note the Relative Cleanliness of the Matrix of this Slowly Cooled Melt. × 500. Fig. 47—Photomicrograph of a Part of Fig. 46. × 2500.
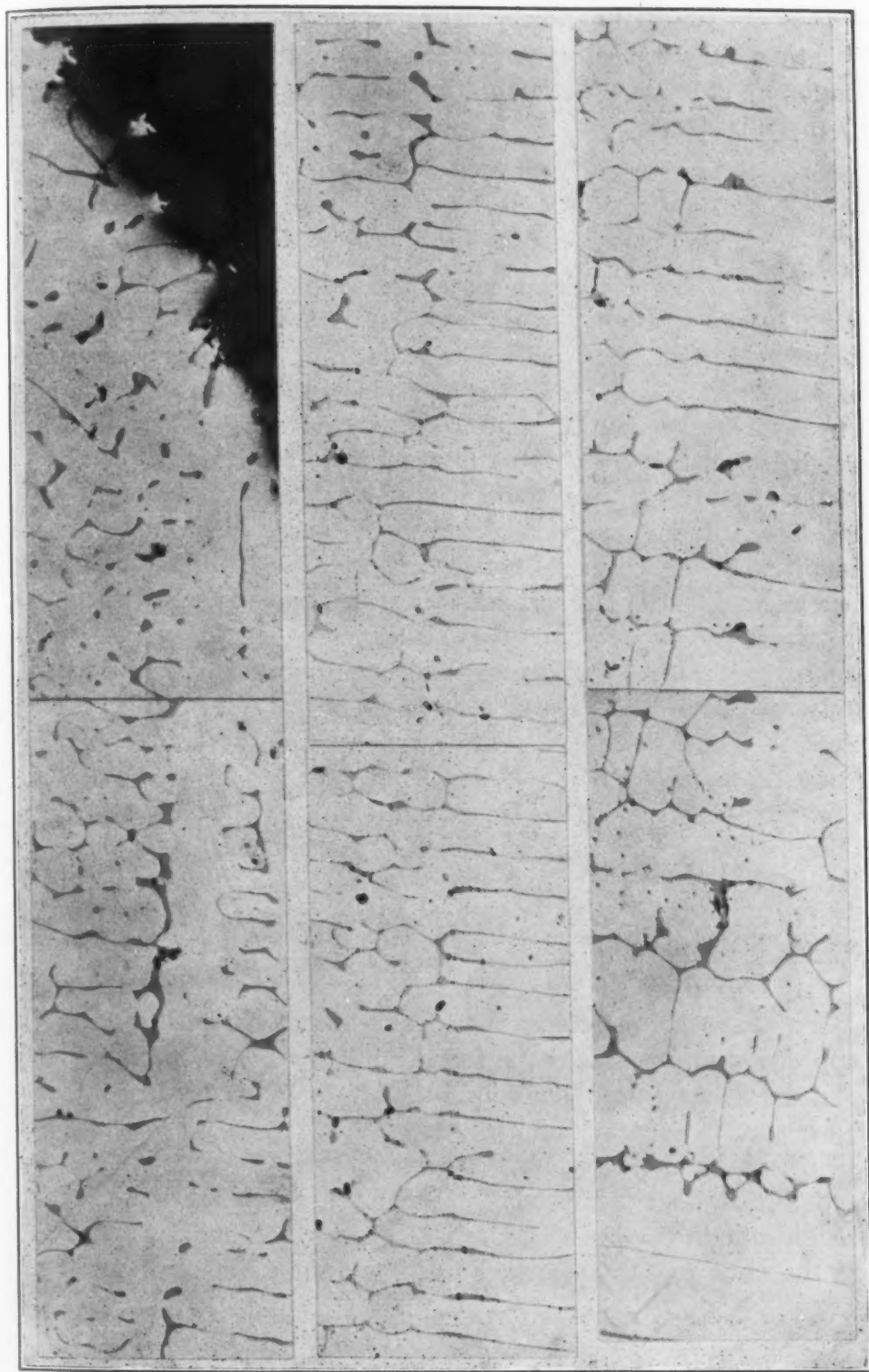
Fig. 48—Photomicrograph of Melt S-1. The Cell Wall Structure and Dendrites. The Sulphide is Located in Dendritic Fillings. × 100. Due to the Length of the Original Photomicrograph this Plate has been Divided into Three Strips. The Top of the Center Strip should Join the Bottom of the First Strip and the Top of the Third Strip should Join the Bottom of the Middle Strip.

and of Arnold and Bolsover (38) ; yet, to the author's knowledge, it has never been successfully applied to a study of the solidification relationships between iron and iron sulphide, to which it is so well adapted.

Mechanism of Solidification of Iron and of Sulphide as Brought out by Sulphur Printing

Fig. 51 is an enlargement of the sulphur print of S-1. The dark areas correspond to the location of the sulphide. The relationship between the sulphide and the iron becomes now apparent at a glance. It is clear in the first place, that pure iron (barring any segregation effects due to dissolved FeS) crystallizes in dendrites, in the second, that iron sulphide solidifies in the fillings of the dendrites, as one would logically expect.

The sulphur printing process, of course, does not preserve details. Silver bromide paper saturated with dilute sulphuric acid is brought in intimate contact with the polished surface of a specimen. As a sulphide particle exposed at the surface is attacked by the acid, it liberates hydrogen sulphide, which immediately reacts with the silver bromide opposite the particle, forming black silver sulphide. The gaseous nature of the reagent implies ready diffusion from the place of its generation;—unless, therefore, the print is well timed, the stain created by the hydrogen sulphide is bound to spread considerably beyond the actual limits of the sulphide particle. In view of this the sharpness of outline exhibited by Fig. 51 is remarkable, especially when the sulphur print is viewed at high magnifications. (Fig. 54).

A Study of Etching Effects. Attempts of earlier investigators[24] to reveal dendrites in iron-sulphur alloys by the ordinary copper plating methods have failed, and this has been interpreted to mean that sulphur (or sulphide) is not dissolved in iron and hence cannot cause dendritic segregation.

The author succeeded, after many trials,[25] in revealing the dendrites by such methods. Fig. 53 shows the dendrites as brought out in S-1 by Le Chatelier's copper reagent (#2). They are the same as those shown by the sulphur print, only reversed

[24]See for example V. N. Krivobok's Thesis on the "Crystallization of Iron-Carbon Alloys," p. 78-9.

[25]The able assistance of C. H. Chou in these trials is thankfully acknowledged.
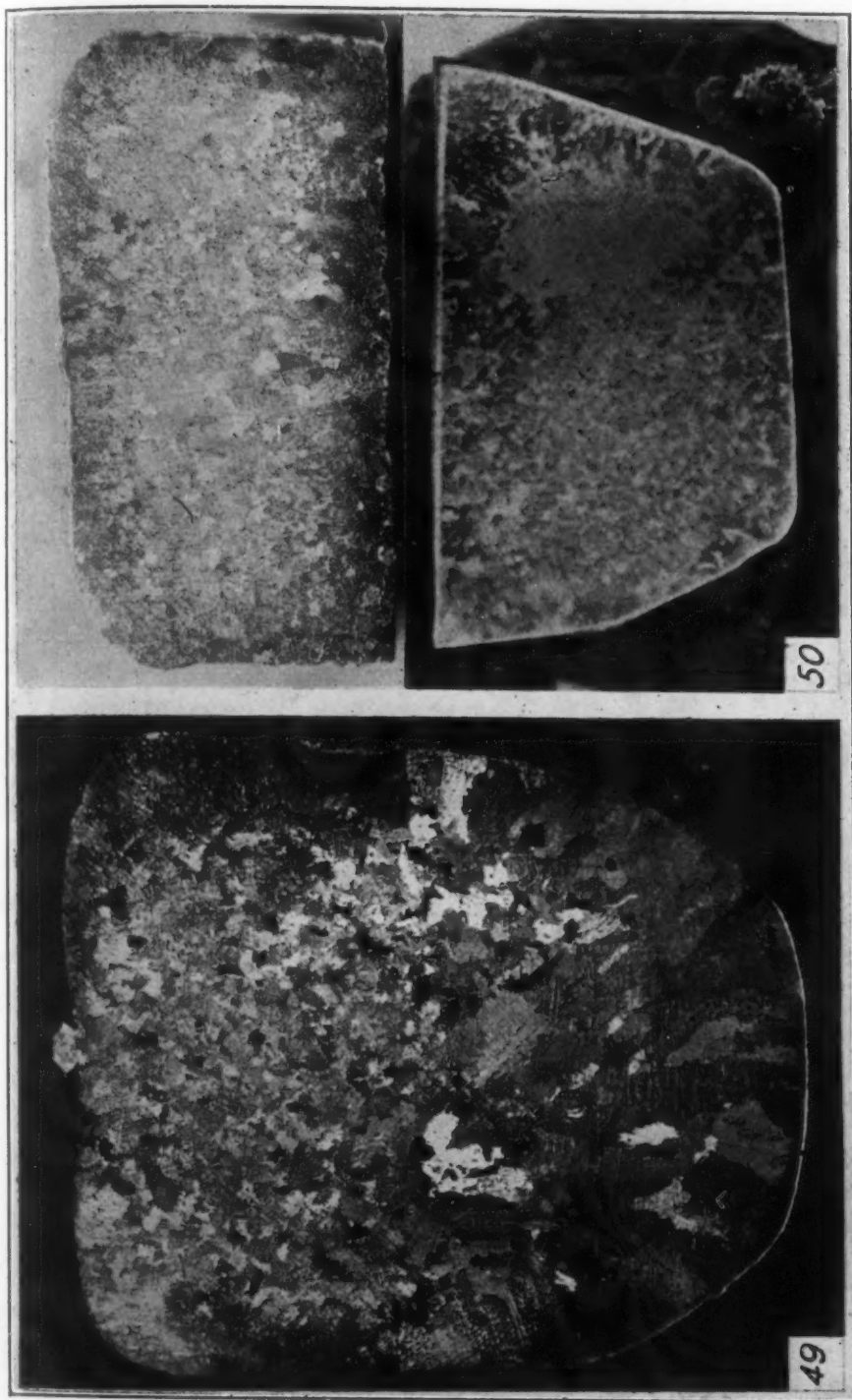
The Macrostructure of High Sulphur Iron. S-1. Fig. 49—Original Grains. Etched 1½ Minutes in 10 Per Cent Nitric Acid. Vertical Illumination. × 3½. Fig. 50—Top Part: Grains After Annealing S-1A. Bottom Part: Grains After Quenching. S-1Q. Etched as Fig. 49. × 3½.
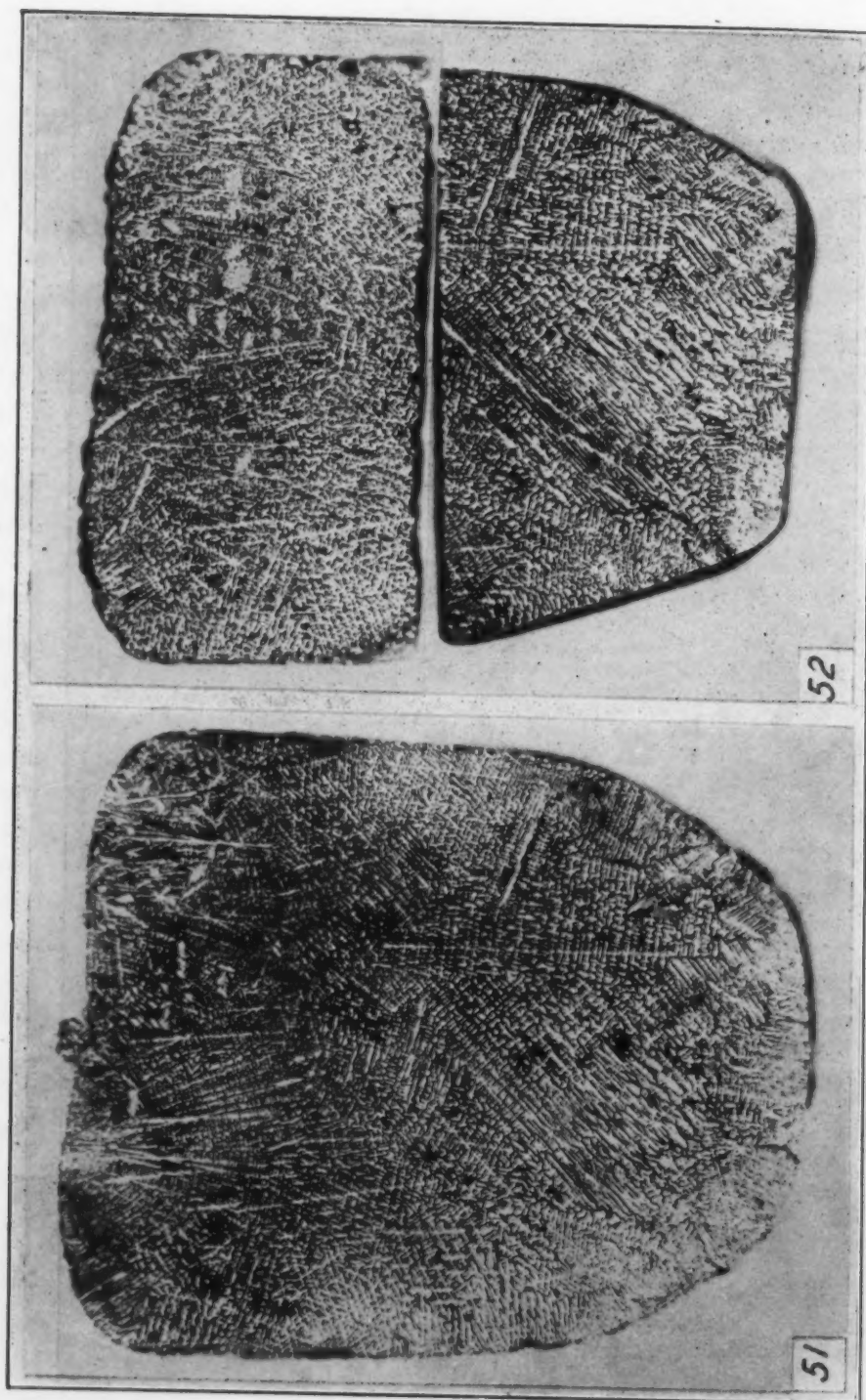
Fig. 51—Magnified Reproduction of Sulphur Print Showing the Relationship of Sulphide and Dendrites. × 3½. Fig. 52—Same as Fig. 51 After Annealing and After Quenching. No Migration of Sulphide has Taken Place. × 3½.

(since the sulphur print gives a mirror image).

Closer study revealed that not only the sulphides but also the areas in the immediate neighborhood of the sulphides were free from copper. This can be accounted for by the existence of sulphide in solid solution in the iron, the less pure portions of the iron being located, of course, in the fillings immediately adjoining the sulphides. It is equally possible, however, that the sulphide interferes in some other way with the normal etching of the adjoining iron.

Sulphur printing with a 2 per cent sulphuric acid solution did not affect the sulphides perceptibly. The latter were blackened however after continued printing with a 10 per cent solution.

Formation of Small Globules. Turning now our attention to the tiny sulphide globules described in earlier pages, what can be said about their origin? There are two possibilities:

(1) They are liberated from the iron on solidification of the latter,—but are, entangled in the rapidly congealing metal and prevented from reaching the main mass of sulphides, rejected to the fillings.

(2) They are precipitated from the metal only after solidification of the latter and remain in situ if the metal is cooled fairly rapidly. On slow cooling they may have some opportunity to diffuse and to coalesce.

Definite conclusions cannot be arrived at on the basis of the limited observations made; inasmuch, however, as solid solubility of sulphide in iron is indicated, and inasmuch as such solubility, undoubtedly, decreases with a fall in temperature, the second possibility is not to be dismissed lightly.

Effects of Heat Treatment. As was mentioned in the review of the work of earlier investigators, the possibility has been entertained that iron sulphide, on heating of the iron, is redissolved by the iron, diffuses through it and finally, on cooling, is precipitated again "in between the crystal grains according to its habit." Heat treatment changes the crystal grains of iron, as is well known; hence one would expect the sulphide, on annealing, to have migrated to new positions. In order to ascertain whether such migration takes place at temperatures employed in practice
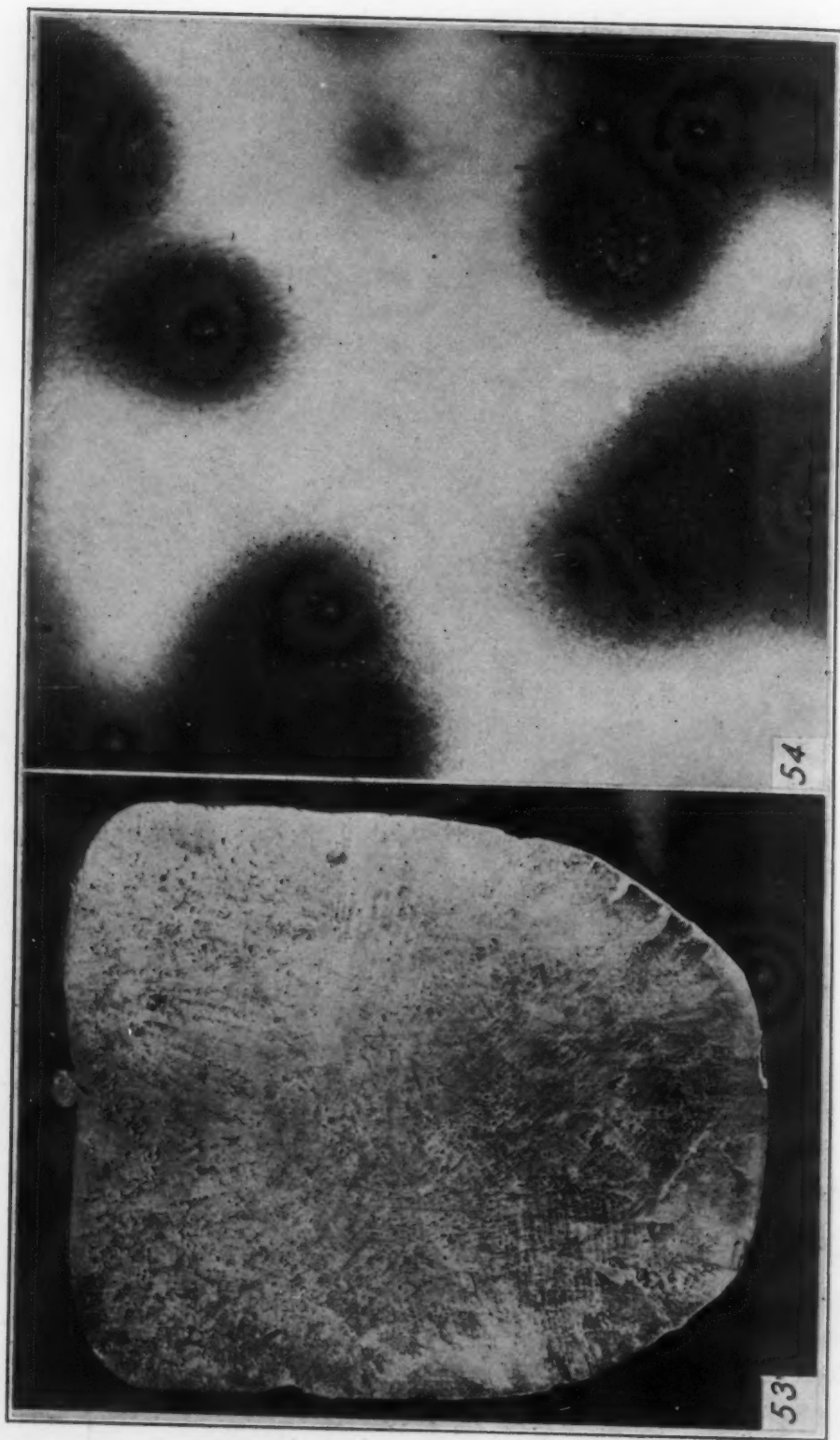
Fig. 51—Magnified Reproduction of Sulphur Print Showing the Relationship of Sulphide and Dendrites. × 3½. Fig. 52—Same as Fig. 51 After Annealing and After Quenching. No Migration of Sulphide has Taken Place. × 3½.

Fig. 53—Dendrites in S-1. Etched with Le Chatelier's Reagent. × 3½. Fig. 54—Magnified Area of the Sulphur Print of Fig. 51. Note the Relative Sharpness of Dendrite Outlines. × 500.

a part of S-1 was kept at 1760 degrees Fahr. (960 degrees Cent.) for one hour, then heated up to 1815 degrees Fahr. (990 degrees Cent.) and quenched, and another part annealed at 1760 degrees Fahr. (960 degrees Cent.) 2 hours and cooled very slowly in the furnace. The micro-distribution of the sulphide in the quenched and the annealed specimens was found to be precisely the same as before heat treatment.

The relative grain sizes before and after heat treatment are shown in Figs. 49 and 50, the top portion of the latter shows the annealed half, and the bottom portion, the quenched half of the specimen. Quenching resulted, as is seen, in a marked grain refinement, while not much change in grain size is apparent in the annealed specimen. The grains, in either case, are different from the original grains, of course.

Figs. 51 and 52 permit a comparison of the sulphide distribution before and after heat treatment. The dendritic structure of the quenched half is seen to coincide with that of the original specimen even in detail and this despite the fact that oxidation necessitated the preparation of a new polished surface with attendant removal of a layer of sulphide and metal. Doubtlessly no migration whatever has taken place; the sulphide remained where it formed,—in the fillings of the original dendrites. The correspondence between the dendrites of the annealed half and the original specimen is not as perfect on account of the heavier layer of oxidized metal that had to be removed; still the correspondence is close enough to warrant the same conclusion.

This is of course what was to be expected. Indeed, why should sulphides migrate? With the increase of the dissolving power of the iron for sulphide at elevated temperatures, a small proportion of the sulphide might be dissolved, of course. But this would merely restore a condition existing in the melt when it originally reached the corresponding temperature, and would, perhaps, eliminate, for the time being, the tiny globules which were found in the iron. It could have no effect at all on a structure created at the temperature of solidification. Nothing short of remelting can be expected to change the distribution of the bulk of the sulphide, for this distribution is a function of the conditions of solidification only. Diffusion has to be reckoned with—but diffusion will take place only if there is a concentration gradient calling for

Fig. 53—Dendrites in S-1. Etched with Le Chatelier's Reagent. × 3½. Fig. 54—Magnified Area of the Sulphur Print of Fig. 51. Note the Relative Sharpness of Dendrite Outlines. × 500.
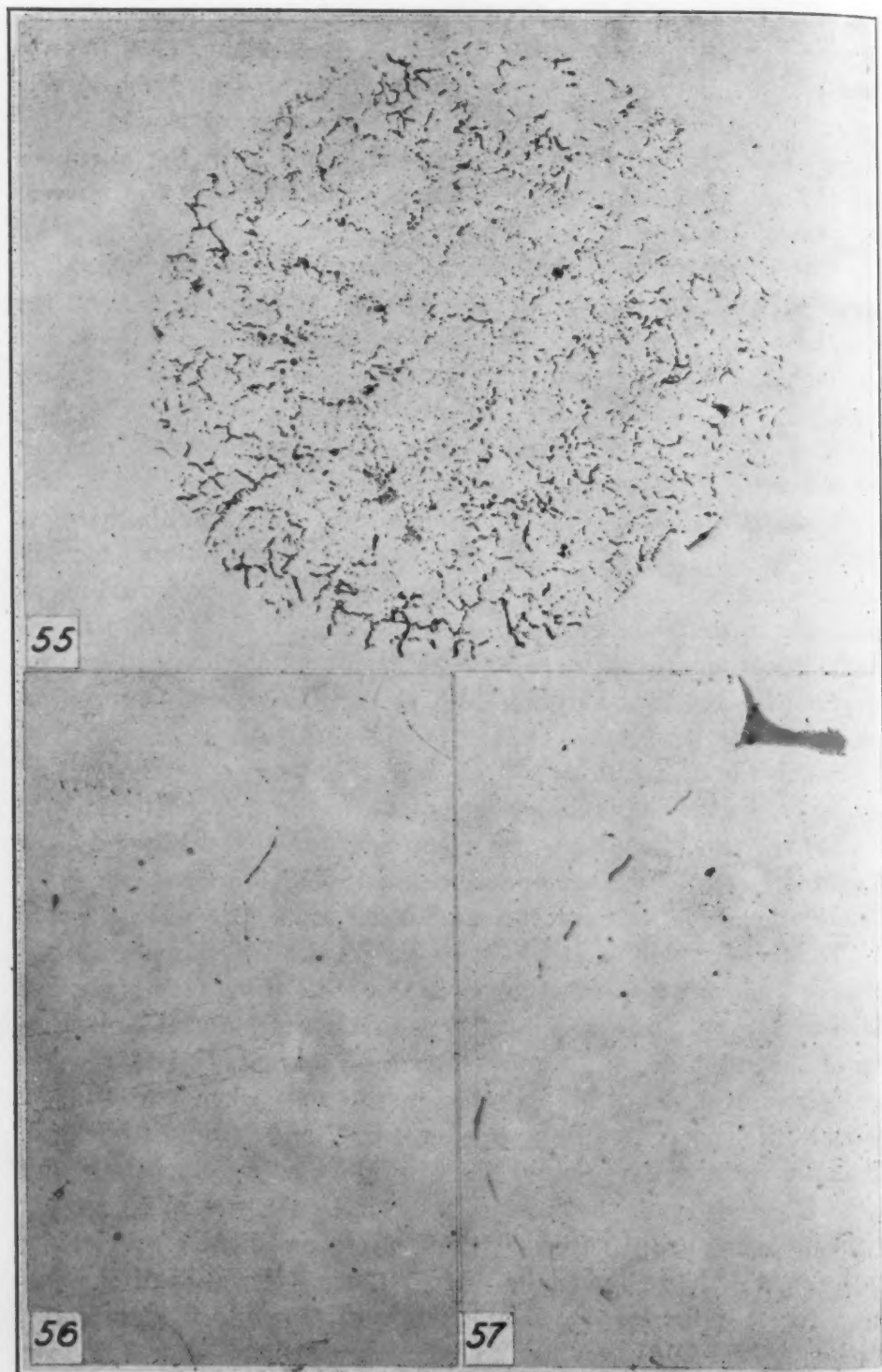
Fig. 55—Magnified Reproduction of Sulphur Print. × 3½. Sulphide Inclusions in Low Sulphur Iron. S-3. Fig. 56—Typical Appearance at 100 Diameters. Fig. 57— Tendency to Form Continuous Envelopes is Locally Shown. × 500.

it, or a special influence inducing it. No such gradient exists here, the metal throughout the ingot being saturated with all the sulphur it can hold in solution; nor is the presence of any special causes for diffusion indicated.

THE MEDIUM AND LOW SULPHUR MELTS
(S-3, S-4 and S-5)

The next melt prepared (S-3), containing in the neighborhood of 0.1 per cent sulphur, substantiated, in a general way, the conclusions arrived at from a study of the high-sulphur melt.

Sulphur Prints and Macrostructure. An enlargement of a sulphur print of the cross section of this melt is shown on Fig. 55. Corresponding to the lower percentage of sulphur the print appears much fainter than the prints of the previous case. Dendrites, at a first glance, appear not to be brought out; instead we observe the dark sulphide lines to circumscribe rather irregular areas. These areas correspond to the original dendritic grains of the ingot, now no longer existing, and the sulphide appears at the boundaries of these grains for the same reason that it appeared in the fillings of the dendrites in the previous case. These boundaries, in fact, are the last dendritic "fillings", as it were, since they represent the places where the last liquid material solidified. Closer inspection of Fig. 55 reveals that, after all, the dendritic outlines are brought out, though only faintly, being traced by tiny sulphide particles located in the fillings of the dendrites. There was not enough sulphide available, in the present case, to give a clearer picture of the dendrites.

Description of Inclusions. Microscopic examination of the unetched specimen at $\times$ 100 shows the relative cleanliness of this melt (Fig. 56). The majority of the inclusions appear here in the form of small rounded sparsely scattered globules seldom exceeding 0.01 millimeters in diameter; occasionally more or less continuous extremely thin streaks are observed. Only at high magnification does the presence of considerable sulphide become noticeable. Minute globules of the order of 0.0001 to 0.001 millimeter in diameter are plentiful. The tendency of the sulphide to form envelopes is also exhibited. These envelopes are incomplete in most instances, appearing in the form of a series of interrupted small streaks, or in a series of globules as shown in Fig. 57 and Fig. 60. Not infrequently such incomplete "envelopes" can
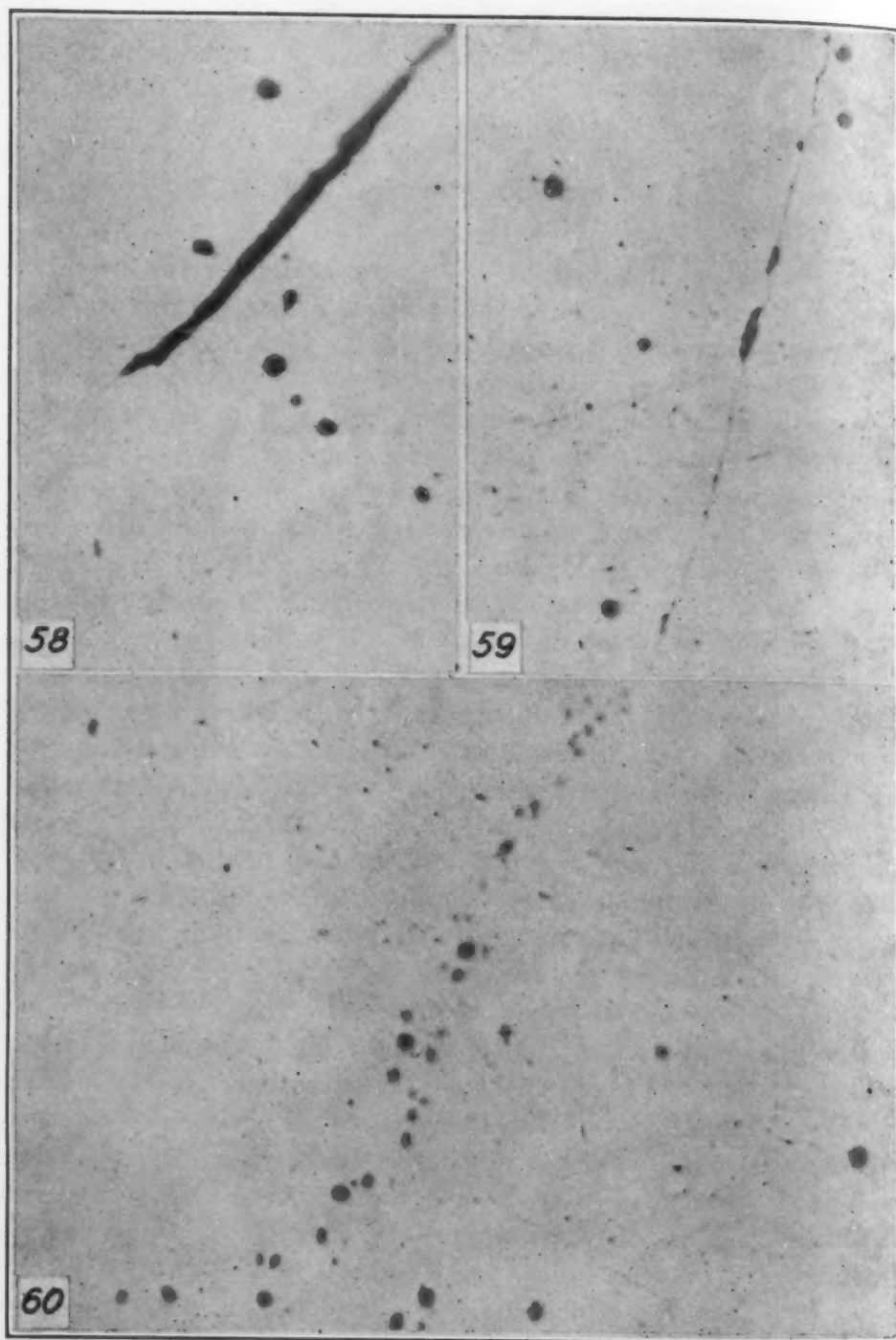
Sulphide Inclusions in Low Sulphur Iron. S-3. Figs. 58 and 59—Extremely Thin Sulphide Lines are Seen to Connect Larger Sulphide Inclusions. × 2500. Fig. 60—A sulphide "Envelope" Formed by Tiny Globules. × 2500.

be traced for considerable distances along the specimen.

Occasionally hair-like sulphide lines connect the larger inclusions (Fig. 59), and these lines are, at times, so fine that they can be discerned only with the greatest difficulty even at magnifications as high as × 2500 (Fig. 58). The significance of these sulphide "lines" is obvious from the preceding; they represent the junctions between two dendrites to which the sulphide, precipitated from solution, was rejected. The "lines" are thin because there is not enough sulphide to make them heavier.

The next lower sulphide melt (S-4) analyzed 0.033 per cent sulphur which corresponds to less than 0.1 per cent FeS. No inclusions could be found in this melt, even at the highest powers of the microscope, although specks suggesting inclusions were observed here and there. And, of course, in the last melt (S-5) which contained but 0.016 per cent sulphur no inclusions could be found either.

In both cases sulphur printing failed to discolor the silver bromide paper.

Solubility of FeS in Fe. It appears indicated that iron, in the absence of other elements, is capable of holding 0.02 per cent sulphur (or some 0.05 per cent FeS) in solid solution at atmospheric temperature. Solid solubility of sulphide in iron is also suggested by the effects of some etching reagents, notably the copper reagents, as was already shown, and of picric acid. [Le Chatelier and Ziegler (16)]

In any case this solubility is very small and gets still smaller in the presence of certain elements, such as manganese and oxygen. In ingot iron, for example, which contains but 0.02 per cent sulphur, sulphides are clearly recognizable, while in iron with this same percentage of sulphur, but free from oxygen none was observed.

Before leaving the subject of pure iron sulphide inclusions it might be well to consider a few aspects of these inclusions which the preceding photomicrographic studies failed to bring out. In particular, the system Fe-FeS and the question of the Fe-FeS eutectic, which is universally believed to exist, is deserving of attention.

The System Fe-FeS

The system Fe-FeS was first studied in detail by Treitschke

and Tammann (23) who constructed the equilibrium diagram reproduced in Fig. 61. Later, K. Friedrich (50) checked the work of Tammann, using purer materials and experimenting with greater care. He found that Treitschke and Tammann were in error in many important points and submitted the diagram shown in Fig. 62. Friedrich's work has been largely overlooked, later
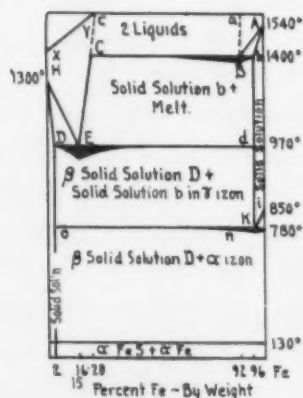
Fig. 61—Fe-FeS Equilibrium Diagram by Treitschke and Tammann.
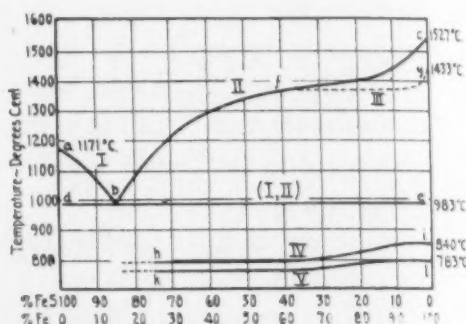
Fig. 62—Fe-FeS Equilibrium Diagram by Friedrich.

writers referring, in most instances, to the diagram of Treitschke and Tammann. We are, therefore, justified in giving our attention to this diagram first.

Treitschke and Tammann's Diagram. Not many steels are met with that carry over one per cent sulphur, (which corresponds to about 2.75 per cent FeS). It is, therefore, only the extreme right portion of Tammann's FeS-Fe equilibrium diagram that is of practical interest. According to this portion of the diagram, and explanatory statements in the original text, melts containing from 0 to 4 per cent FeS form solid solutions of the composition of the melt. These solid solutions persist until they reach the line ik (temperature range 850 to 750 degrees Cent.) where separation of pure alpha iron takes place, the remaining solid solution becoming richer and richer in FeS until a 7 per cent FeS content is reached. The solution then breaks up into FeS and beta iron, according to Tammann. Lastly, at 128 ± 5 degrees Cent. an allotropic transformation of beta-FeS into alpha-FeS takes place, a transformation which had been noted already by Le Chatelier and Ziegler (16) in the course of dilatometric observations.

Tammann's conclusions are, clearly, not in accord with the

facts. The observations of the author, and of many other inves-
tigators, if properly interpreted, show that iron while passing
from the liquid to the solid state loses its dissolving power for
most of the sulphide which, accordingly, is rejected to the dendritic
fillings and to the boundaries between adjoining iron dendrites.
It will be remembered that inter-dendritic sulphide envelopes were
obtained with a sulphur concentration as low as 0.1 per cent, cor-
responding to some 0.28 per cent FeS. We are justified then in
concluding that iron, immediately after solidification is capable
of dissolving materially less than 0.3 per cent FeS and surely
not up to 4 per cent FeS, as is suggested by Treitschke and Tam-
mann.

Contrary to accepted views [Levy (29), Ziegler (31), Röhl
(37)], it does not follow from Treitschke and Tammann's diagram
that sulphide inclusions are made up of a Fe-FeS eutectic.

Treitschke and Tammann, in fact, make no mention of a Fe-
FeS eutectic for the case of iron containing less than 4 per cent
FeS which is the only case important in practice.

Diagram of Friedrich. The eutectic nature of iron sulphide
inclusions follows, however, from the diagram of Friedrich (95)
which, in the opinion of the writer, is a far more accurate and
reliable diagram than the one just described (Fig. 62). In fact,
Friedrich has shown (50) that many of the complications pic-
tured by Tammann were attributable to the presence, in his melt,
of oxide.

The main points of Friedrich's diagram as contrasted with
Treitschke and Tammann's diagram are:

(1) There is no separation into phases of the liquid
melt.[26]

(2) Solid solutions of FeS in Fe and Fe in FeS (of
noticeable concentration) are absent.

(3) Practically pure iron separates, in iron-rich melts
(and practically pure sulphide in sulphide-rich
melts) until the melts reach the eutectic composition:
—(15 per cent Fe, 85 per cent FeS). This eutectic
solidifies at 1800 degrees Fahr. (983 degrees Cent.)

(4) No subsequent changes of importance are noticeable,

[26]This was recently substantiated by Bogitch (53).

> the thermal effects at 840 and 783 degrees Cent. being ascribable to the allotropic changes of the iron.

The author's observations, in a broad way, are in accord with Friedrich's tentative conclusions, except for the fact that no evidence of a Fe-FeS eutectic was found.

The Fe-FeS Eutectic. This eutectic, in sulphide inclusions, has never been seen by other investigators either.

> Thus, G. Röhl (37) states:
>> ". . . this eutectic is so infinitely fine that it is not possible to resolve it into constituents when cooled normally, even when high magnifications are employed."
>
> M. Ziegler (31) admits that:
>> "En examinant la surface de l'eutectique fer-sulfure dans le fer et l'acier sous un agrandissement aussi fort que possible, il ne m'est pas arrivé une seule fois d'y observer du fer d'un caractère eutectique, tant ce eutectique est fin."

Both Ziegler and Röhl examined the structure of melts containing in the neighborhood of 85 per cent FeS (the theoretical amount for the eutectic) and both present pictures of this eutectic the structure of which is quite well developed. Curiously enough they seem to find it quite in order that the eutectic, here, is visible at relatively low magnifications, although, according to their own testimony, this eutectic is ordinarily exceedingly fine by habit.

As the author sees it we have either no eutectic at all when dealing with low percentages of FeS, or, what is more probable, the components of this eutectic divorce and coagulate with such readiness (in the presence of excess iron) that the structure cannot be preserved, even on rapid cooling.

4. Manganese Sulphide (+ Iron Sulphide) and Iron

It appeared desirable to consider separately the following three cases:

(1) Sulphur in excess of the theoretical amount necessary to form MnS.

(2) Manganese and sulphur in the exact proportion to form MnS.

(3) Manganese in excess of the theoretical amount called for by MnS.

Three melts were prepared in accordance with the above scheme: S-6, S-7 and S-8, the average analyses of which, in terms of MnS and excess Mn and S, were found to be as follows:

(1) S-6 .... MnS 1.61%　　S 0.16%
(2) S-7 .... MnS 1.71%　　Mn 0.45%
(3) S-8 .... MnS 1.09%　　Mn 5.7 %

Elemental sulphur and manganese were charged into the electrolytic container in powdered form, layers of sulphur alternating with layers of manganese. The sulphur and manganese were thus in contact with each other and with the iron as well, and ample opportunity was given for these elements to establish preferred unions.

THE EXCESS SULPHUR MELT (S-6)

Distribution of Manganese and Sulphur. The excess sulphur of S-6 was expected to form FeS which either would appear as a separate constituent alongside with MnS, or else form a solid solution with MnS if such solutions existed. The MnS, in view of its undisputed insolubility in iron and its inferior density, would, furthermore, be expected to float to the top of the melt, leaving the bottom part of the ingot relatively free of sulphide. The top portion of the resulting ingot, indeed, was found to be very much richer in manganese than the bottom part, the sulphur, however, strangely enough, did not seem to follow the manganese. The analyses are given in Table II. Recalculated in terms of MnS and FeS, and excess manganese, we have:

	Top fourth	Bottom fourth
MnS	2.15%	0.92%
Mn	0.11%	...
FeS	...	1.02%

Such calculations do not apply to the actual case as is evident already from the fact that notable amounts of FeS were observed near the top of the ingot. This means that a considerable proportion of the sulphur allotted to the manganese is, in fact, combined with the iron. The percentage, then, of free metallic manganese must be much higher than would appear from the calculations. This in turn makes the presence of FeS still more of a puzzle.

Description of the Inclusions. Figs. 63-66 illustrate the representative structures observed in passing from the top of the

ingot to the bottom. The contrast between the top and bottom
structures (Figs. 63 and 66) is striking,—the transition is, how-
ever, very gradual as is illustrated by the intermediate Figs. 64
and 65. Near the top we have a structure first depicted by Le
Chatelier (16), and later described in detail by Arnold and Bol-
sover (38). Two constituents are distinctly discernible under the
microscope (Fig. 67). A pale yellow constituent, concentrated
mainly in the clear cut though interrupted streaks or cell walls,
and a dove gray one appearing in the cells in the form of tiny dots
or globules which grow and become somewhat elongated on ap-
proaching the cell walls. The yellow constituent is, without doubt,
FeS or a solid solution rich in FeS, while the gray one is either
MnS or a solid solution rich in MnS. The brilliancy of these
two constituents is so alike that a differentiation of them on a
photographic reproduction is impossible unless a special color fil-
ter is used in making the picture. The author used a red filter
which renders the gray sulphides darker than the yellow ones.
Photomicrographs prepared in this manner are presented on Figs.
68 and 69, which serve to illustrate the observed relationships in
further detail.

The Fe-MnS Eutectic. If we were shown the middle portions
of the meshes depicted in Figs. 63 and 67, and were asked what
the structure signifies we would be tempted to-say that it represents
a eutectic of some sort or another. In the opinion of Arnold and
Bolsover (38), these groups of manganese sulphide dots and dashes
radiating from a center "form strong evidence of the presence
of a eutectic of ferrite and manganese sulphide existing whilst the
steel was in a fluid condition and which falls out on (or possibly
before) the solidification of the steel in rounded masses, which
eventually decompose into their eutectic components. In all big
ingots it is probable that the small manganese sulphide particles
of the eutectic mixture ball up into relatively large masses and the
eutectic structure disappears."

We cannot agree with Arnold in his notion that a eutectic
which solidifies earlier than one of its components can exist; we
must agree, however, with the observation that the structures
exhibited are, indeed, suggestive of a eutectic.

A eutectic implies two things:

(1) Simultaneous crystallization of its components.
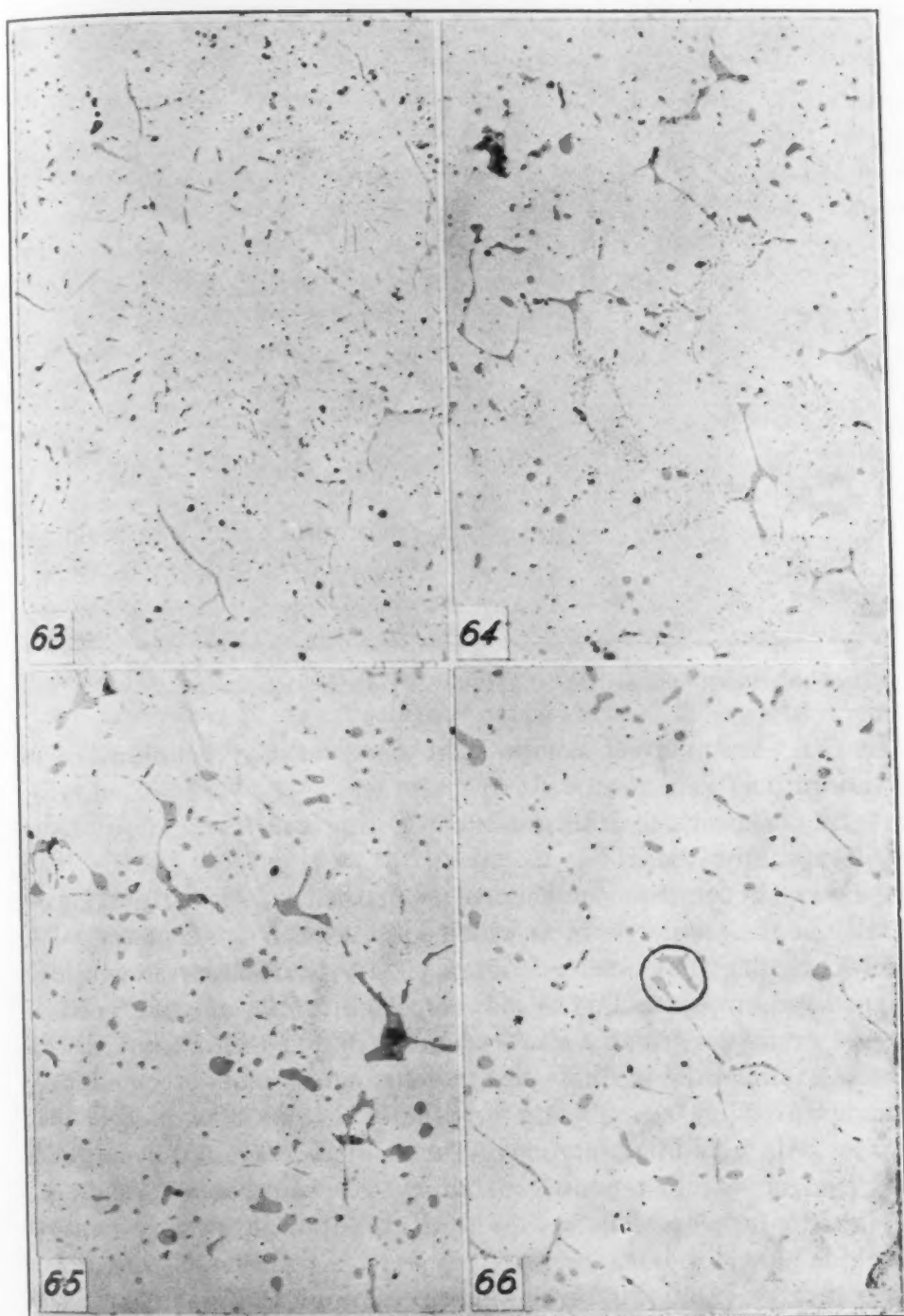
Variation in Sulphide Structures of the Ingot S-6. Fig. 63—Structure Near the Top. × 100. Fig. 64—Structure Toward the Middle (About ⅓ from the Top). × 100. Fig. 65—Structure at the Middle. × 100. Fig. 66—Structure Near the Bottom. × 100. Note: Figs. 64 and 65 were Photographed After Annealing and Quenching of the Ingot. These Treatments did not Affect the Structure However.
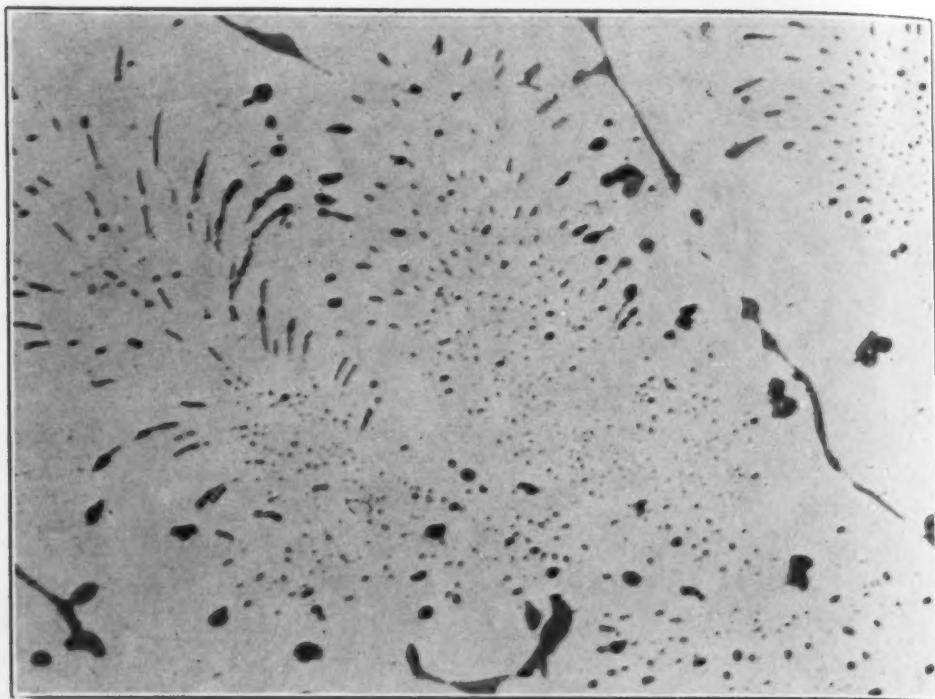
Fig. 67—"Dots", "Dashes" and "Cell Walls" of FeS-MnS Inclusions in Melt S-6.　× 300.

(2) Constancy of composition (and of the temperature of solidification).

Simultaneous crystallization of the iron and the gray sulphides is clearly indicated.

What about the constancy of composition, especially the constancy of the temperature at which solidification takes place? The centers of the "dot clusters" mark clearly the centers from which crystallization started. The sulphide dots in the neighborhood of these centers are usually small and distributed uniformly. As we proceed toward the periphery of the clusters the dots become larger and more widely spaced, and eventually assume elongated shapes arranged in a fan-like manner. The relative amounts of sulphide and iron appear to remain constant which would tend to support the existence of a eutectic. The composition of the individual sulphide particles, however, does not seem to remain constant (as is suggested by faint differences in the color of the globules in the center and that of the ovoids nearer to the periphery). The temperature of solidification, then, cannot remain constant throughout the solidification period of any one mesh, either.

What we have is probably not a eutectic in the strict sense of the word. We have simultaneous crystallization of two components with a gradual change in composition of both. The iron gets richer in dissolved impurities, probably; while the sulphide gets richer in FeS content. The cell walls, as in the case of the pure iron sulphide melts, represent the last portions to solidify and mark, consequently, the dendritic fillings and inter-dendritic boundaries.

The theory of simultaneous crystallization of sulphide and of iron implies the presence of sulphide in the axes of the metal dendrites as well as in the fillings. This is verified by the sulphur print of the top section of S-6 (Fig. 71). Suggestions of dendrites are discernible here and there in the print,—on the whole, however, the picture is confused.

Constitution and Occurrence of Inclusions. Let us examine now the probable constitution of the sulphide inclusions. The gray sulphide globules can hardly be pure manganese sulphide. In the first place these globules were apparently in solution in the iron while manganese sulphide is supposedly insoluble in iron; in the second, they have a solidification point not unlike that of iron, while MnS, according to many, solidifies much earlier. The melting point of MnS is still being disputed, however; it also might be contended that the sulphide globules seen are the products of a reaction of Mn and FeS—both of which are dissolved in the iron—a reaction which takes place only at the instant of solidification of the iron.

Such contentions fail to account for the slight but consistent change in color of the gray sulphides. This consistent change in color can be caused only by a similarly consistent change in composition,—a change which, by the way, terminates in pure or nearly pure FeS. There is hardly any doubt that we are dealing here with a series of solid solutions of FeS in MnS. The higher the FeS content of the solution the lower its melting point and the lighter its shade.[27] And while MnS is insoluble in molten iron, MnS + FeS or its equivalents may well be.

The series of the FeS-MnS solid solutions is not a complete one; as a more or less abrupt change in color from a very pale gray to a pale yellow takes place at some intermediate concentration. This change is illustrated by Figs. 68 and 69. The darker constituent is pale gray, the lighter pale yellow. Not all the cell walls

[27]It must be noted that the differences in shade are apparent, to a trained eye, only in a well prepared specimen and only after a prolonged study of the specimen.
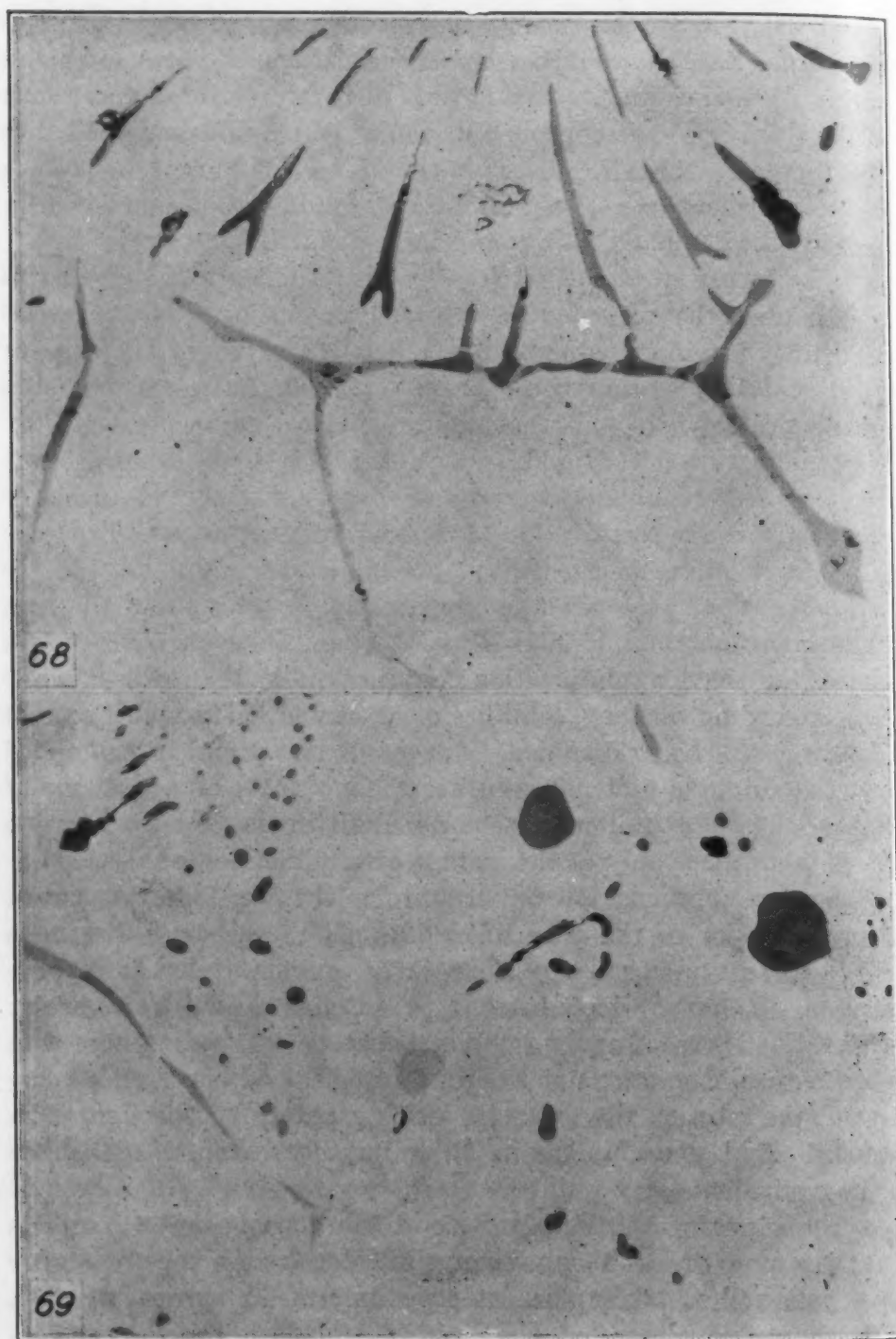
Figs. 68 and 69—Duplex Structure of the Cell Walls and Yellow and Gray Inclusions in Melt S-6.   Red Filter.   The Lighter Areas are Yellow Suphide, the Darker—Gray Sulphide. × 500.

show a duplex structure—a few appear yellow throughout, and in some cases even globules of uniformly yellow FeS can be seen in close neighborhood of gray MnS-rich globules as for example in the center of Fig. 69.

This latter relationship becomes increasingly more frequent as we proceed toward the bottom of the ingot. The eutectic clusters of fine dots become less and less frequent, being gradually replaced by an apparently irregular aggregate of much larger globules which, in turn, gives way to globules arranged in orderly patterns, fully analogous to the continuous cell wall patterns, of S-1 (Figs. 58-60). At the same time the color of the inclusions changes. Lighter grays become the rule and more and more yellow becomes apparent.

The orderly arrangement of the sulphide globules suggests that they are located in the dendritic fillings. Sulphur printing proved this to be the case.

Duplex Structure of the Inclusions. Reference was already made to the duplex structure of the cell walls in the top portion of the ingot. A similar joint occurrence of faint gray and pale yellow constituents is not infrequent in the rounded globules prevalent in other parts of the ingot. Most commonly a gray globule is seen to be surrounded by a yellow envelope; occasionally, however, more complex structures, such as depicted in Fig. 70, are met with.

It can be predicted that heat treatment of such inclusions will result in a great variety of structures depending on the nature of the treatments. Quenching, probably will preserve a uniform solid solution, supersaturated at atmospheric temperature; subsequent moderate annealing will result in a separation of the constituents of the solution, perhaps in a Widmanstätten pattern or a related form; prolonged annealing, in complete divorce.

Effects of Heat Treatment. Heat treatment of the specimen did not result in any changes in the distribution of the inclusions, as is seen from Figs. 64 and 65.

Whether or not changes had taken place in individual inclusions could not be ascertained definitely since inclusions studied prior to heat treatment could not be preserved for examination after the treatment. Oxidation, attendant to annealing, introduced in fact more complications than those which arose from the necessity to prepare a new polished surface for examination. The changes effected by oxygen will be discussed in the next chapter.
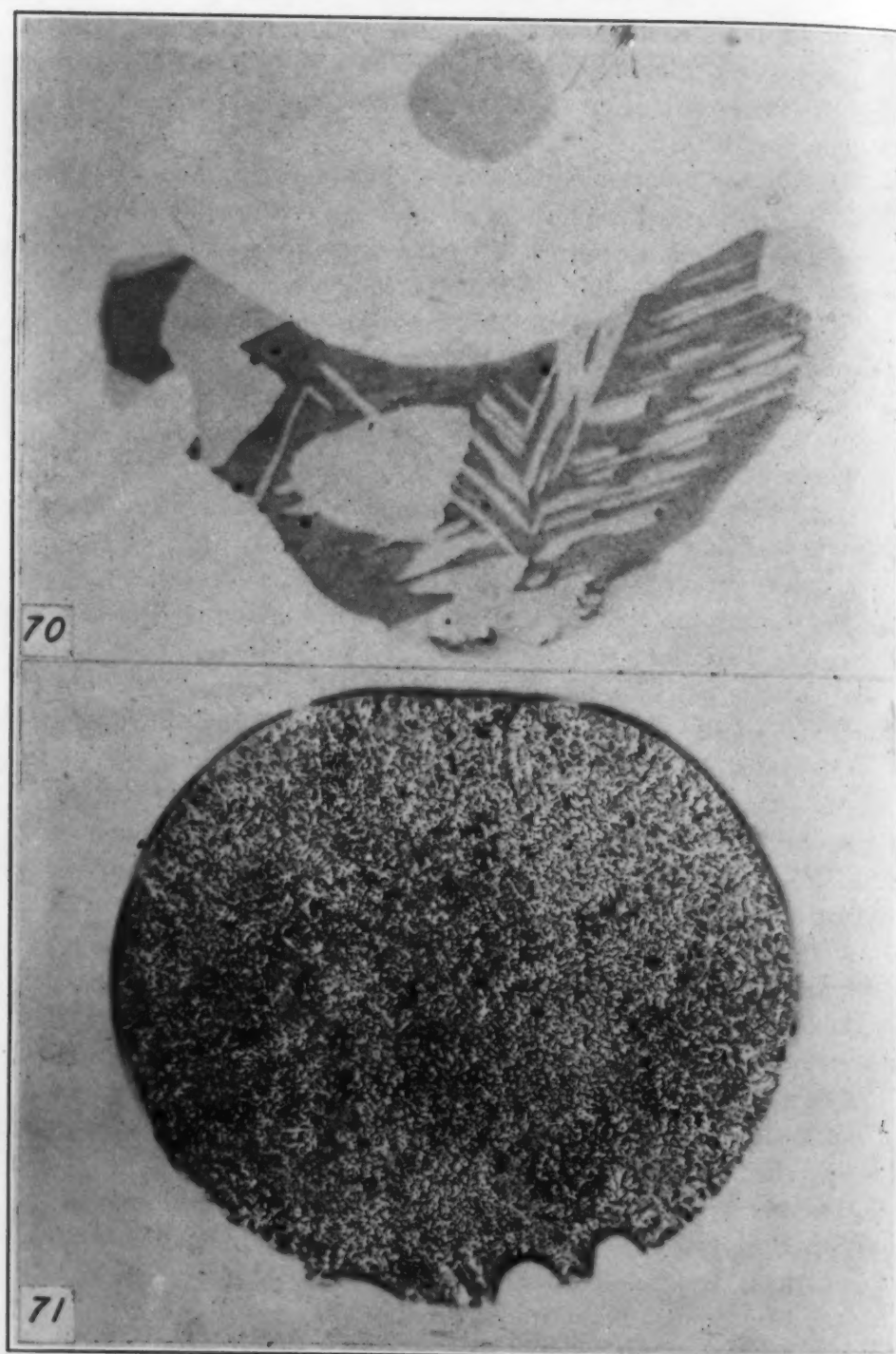
Fig. 70—Melt S-6 (S-6A). Annealed. Red Filter. Widmanstätten Patterns in FeS-MnS Inclusions. The Yellow Sulphide Appears Light. × 2500. Fig. 71—Melt S-6. Sulphur Print at the Top Section. Note the Confused Structure. × 3½.

Apart from these extraneous phenomena the appearance of the inclusions after treatment supported the contention that such treatment has an influence on their structures. This will become apparent when the evidence of Chapter IV is presented.

Identification Tests. It appeared of interest to ascertain whether inclusions exhibiting faint color differences would behave differently under the action of chemical reagents. The typical group pictured in Fig. 73 was selected for a first trial. The largest inclusion in the middle of the photograph is pale gray, the two globules immediately below and to the right have a yellowish rim while the two globules further above and to the right are again uniformly pale gray. The elongated inclusion above is uniformly pale yellow and the two inclusions in the right upper corner of the picture are uniformly yellow and uniformly gray respectively. Fig. 74 shows the same inclusions after five minutes etching in a 10 per cent solution of chromic acid in water—a solution recommended by Campbell and Comstock (49) for the identification of manganese sulphide inclusions. Only one of the gray inclusions succumbed to the attack of this reagent, and one—the large inclusion—showed signs of weakening.

Next sulphur printing for 20 seconds (using a 2 per cent H_2SO_4 solution in water) was resorted to. This treatment eliminated successfully all gray inclusions (Fig. 75,) leaving the yellowish ones fully intact, even the narrow yellow rims of the duplex inclusions. The action of sulphur printing is further illustrated by Fig. 72. Only the pure or nearly pure FeS is seen to be preserved.

Sulphur printing for 20 seconds with a 2 per cent H_2SO_4 solution apparently destroys all sulphide solid solutions preserving merely the pure FeS, while chromic acid attacks only the solid solutions rich in manganese sulphide. Further tests substantiated these conclusions. A means of differentiation between manganese-rich and manganese-poor sulphide solutions is thus afforded.

Unfortunately, sulphur printing cannot serve as a qualitative test for mixed sulphide inclusions, since it destroys, as was seen in Chapter II, solid solutions of oxides also.

THE MELT WITH THE THEORETICAL AMOUNT OF MANGANESE
(S-7)

Study of a longitudinal section cut through this melt revealed
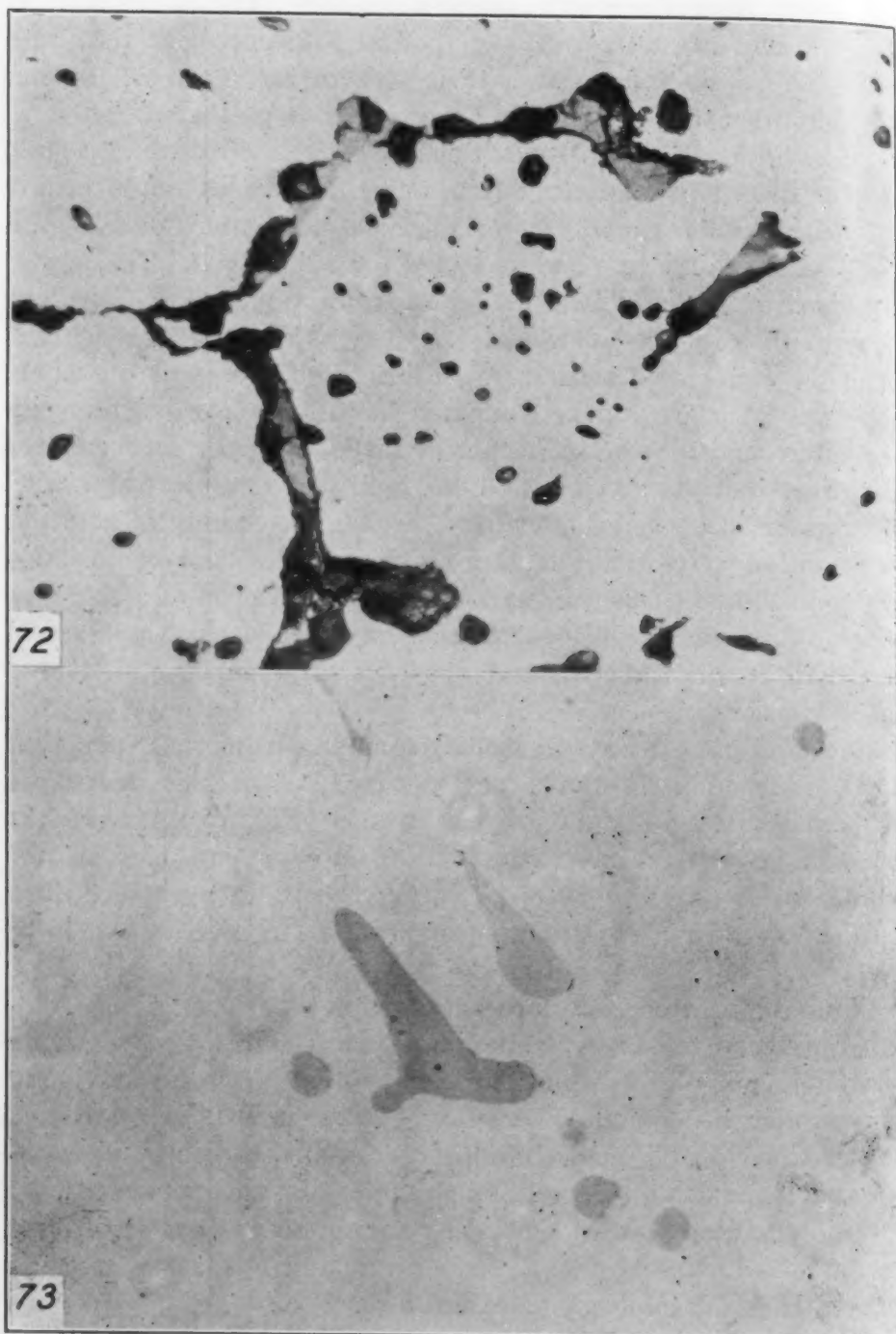
Fig. 72—Effect of Sulphur Printing on FeS-MnS Inclusions in S-6. All Gray Sulphides are Detroyed, the Yellow Ones Only Survive. ✕ 500. Etching Studies on FeS-MnS Inclusions in S-6. Fig. 73—A Selected Spot (Within Fig. 66). Red Filter. Yellow, Gray and Duplex Inclusions. ✕ 500.

Etching Studies on FeS-MnS Inclusions in S-6. Fig. 74—The Same Spot as Shown in Fig. 73. After Etching for 10 Minutes with 10 Per Cent Aqueous Chromic Acid. The "Grayest" Inclusions are Attacked. × 500. Fig. 75—The Same Spot After Sulphur Printing for 20 Seconds, Using 2 Per Cent Aqueous Sulphuric Acid. Only the Yellow Sulphide Survived. × 500.

the presence of three more or less distinct zones grading into one another.   The top zone shows dendritic forms of a rich dove gray constituent in a matrix of the eutectic-like "dot" aggregate described earlier.   The middle zone exhibits only the fine "dot-type" structure while the bottom zone contains larger sulphide globules, much like the ones of the bottom portion of the previously described melt S-6.

Description of the Inclusions in the Top Zone.   A concentration of manganese toward the top of the ingot has, clearly, been effected.   Note the perfect dendritic forms found near the top of the ingot (Figs. 77-78).   They must have crystallized from the melt prior to the solidification of the latter.   How could they otherwise have developed and grown undisturbedly to the extent shown?   It appears to the writer that in these dendrites we meet for the first time pure MnS, although it is, of course, quite possible that even these dendrites contain some FeS in solid solution.

In any case it is evident that pure MnS has a solidification point higher than that of iron, because (1) sulphide dendrites consisting essentially of MnS have solidified before the iron solidified. and (2), the melting point of MnS can only be lowered by admixture of FeS.

Why did these dendrites concentrate near the top of the ingot? Did segregation take place already in the liquid melt, a layer rich in the dissolved components necessary -for the formation of MnS forming at the top of the melt; or did the dendrites float to the top after having formed in lower regions of the melt?   The manner of occurrence of the large rounded globules of MnS (Fig. 76) found at the surface of the melt suggests definitely that they were not born there.   The fact that these globules show only faint beginnings of coalescing suggests further that they were essentially solid at the time they reached their present location.   The dendritic crystals do not seem to form a definite system, but show rather a haphazard distribution.   In all probability the concentration of MnS toward the top of the ingot took place both due to segregation in the melt itself, and due to a floating to the top of solid MnS.   It is possible that on reaching their present location the MnS dendrites continued to grow extracting some of the MnS from their immediate surroundings.   This, in fact, is suggested by the absence of the "eutectic" structure in the immediate neighborhood of some of the dendrites.
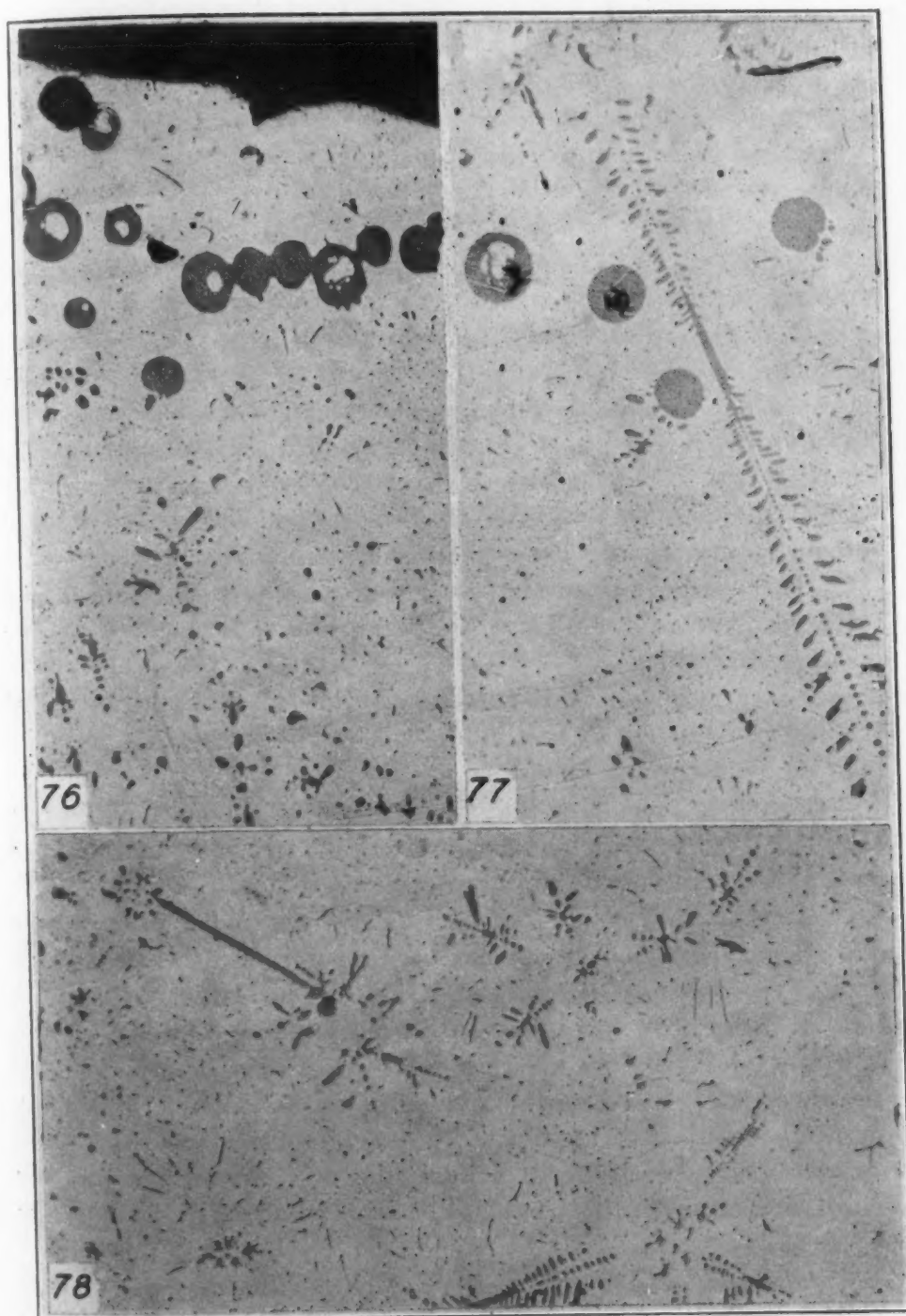
"Manganese Sulphide" Dendrites in S-7. Fig. 76—Dendrites, Dot-Clusters and Semi-Coalesced Large Globules at the Very Top of the Ingot. × 100. Fig. 77—Another Spot Near the Top. × 100. Fig. 78—Dendrites Further Below the Top. × 100.

The pseudo-eutectic, here, differs from that of the previously described melt (S-6) merely in showing a much smaller proportion of elongated sulphide particles. These latter, as was explained earlier, develop near the periphery of the clusters and signify increasing FeS content in the sulphide solutions there. Their decrease in prominence, in the presence of a larger excess of manganese, was to be expected.

Yellow sulphide is essentially absent, high powers revealing only two or three duplex inclusions over the entire area of zone 1.

Inclusions in the Middle and Bottom Zones. The middle and bottom zones exhibit no novel features. Of interest is, perhaps, one aspect of the pseudo-eutectic not brought out before. Near the walls of the ingot, where dendrites usually develop with especial clearness, the pseudo-eutectic is seen to be located in dendritic fillings (Fig. 79). This suggests that the pseudo-eutectic solidifies at a temperature slightly lower than pure iron. This is in line with what one would logically expect (even of a pseudo-eutectic) and serves to disprove Arnold and Bolsover's notion of the high melting point of this eutectic.

Yellow sulphide makes its appearance at the peripheries of the eutectic clusters of the middle zone; however, is less plentiful than in S-6. Duplex inclusions are frequent.

In the bottom zone individual sulphide globules are larger (Fig. 80), the proportion of yellow sulphide is more marked, and even pure yellow inclusions are occasionally seen.

The Sulphur Print. The entire story of this melt can be seen at a glance from an enlargement of the sulphide print of a longitudinal section of the ingot (Fig. 81). At the bottom we have the familiar light iron dendrites outlined by dark sulphide fillings. The iron solidified first, the sulphide last. In the middle zone the structure is confused,—iron and sulphide solidifying essentially simultaneously. At the top we see again dendrites,—this time, however, black dendrites in a light matrix. These are sulphide dendrites which solidified before the iron which here occupies the fillings.

Etching Effects of Chromic Acid. It was deemed desirable to check the etching effects of chromic acid observed in the case of the previous melt (S-6), and at the same time to observe how easily the manganese-rich dendrites would succumb to this reagent. The
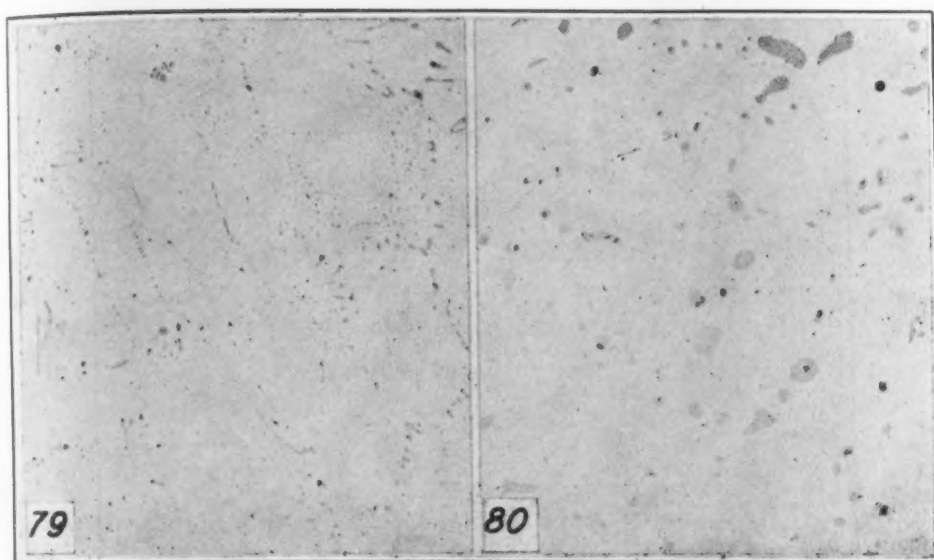
Fig. 79—The Fe-MnS "Eutectic" in Dendrite Fillings in the Upper Portion of the Ingot. (Near a Side Wall.) × 100. Fig. 80—Inclusions in the Lower Portion of the Ingot. They are Larger and Appear to be Distributed at Random. × 100.

results were somewhat unexpected. The fine sulphide particles of zone 1 were darkened, the larger particles, however, and the dendrites, showed merely faint signs of attack. No etching effects at all were discernible in the other zones.   On repetition of the treatment the etch of zone 1 was found to have deepened, in zone 2 the fine "eutectic" inclusions were partially attacked; the rest of the inclusions, however, showed no signs of weakening.

What is the explanation for this? It is well known that the association in which a given metal or mineral is present governs to a marked degree the behavior toward etching reagents of this metal or mineral. If a metal, capable of being attacked by a certain reagent, is embedded in another metal more susceptible to that reagent, then, upon etching, it will generally be found that only the latter metal is attacked. The activity of a reagent is somehow concentrated at places more susceptible to attack, and this is precisely what happened in the present case. The inclusions of the bottom zone are freest from manganese and therefore least susceptible to chromic acid etching. Accordingly the reagent concentrated its efforts on the easier prey.   There may have been, of course, other reasons for the failure of the etching treatment; the case merely emphasizes how unreliable identification methods based on etching effects alone are.
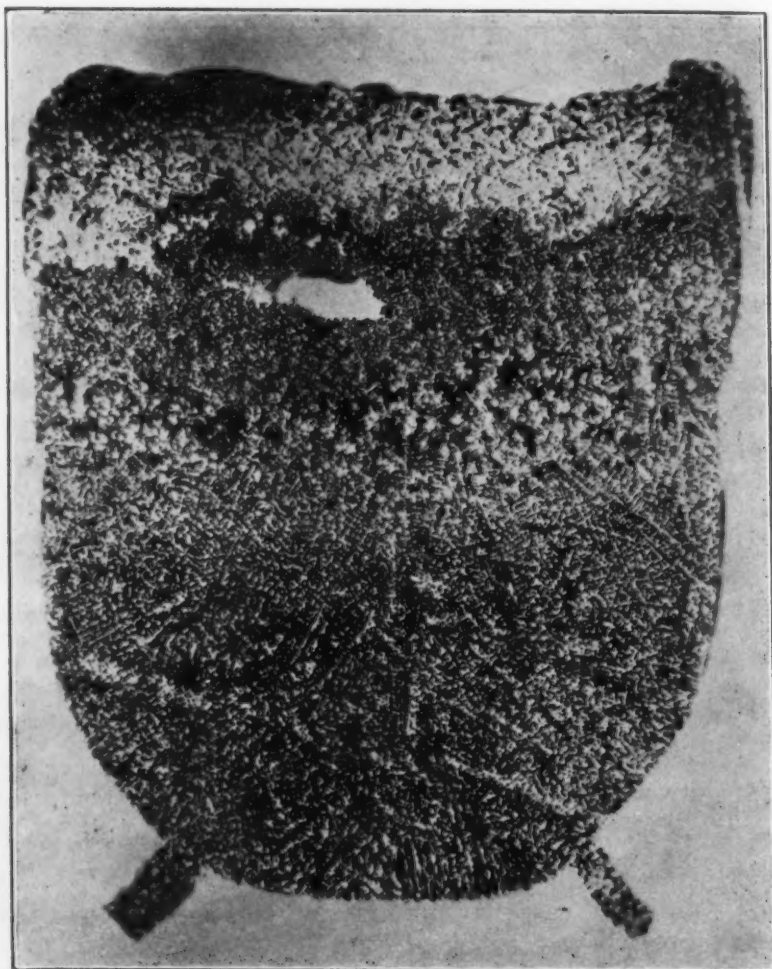
Fig. 81—Reproduction of the Sulphur Print. Note the Black Manganese Sulphide Dendrites Near the Top, the Confused Structure in the Upper Third, and the Sulphide Location in Dendritic Fillings in the Lower Half. × 3½.

The fact that the large MnS particles, notably the bulky dendritic forms, survived an etching treatment which was directed primarily against them illustrates another important point which is not always borne in mind. The relative size of inclusions is a factor that cannot be neglected. A larger inclusion of "weaker" composition may survive an attack which destroys a smaller chemically "stronger" inclusion.

THE MELT WITH A LARGE EXCESS OF MANGANESE
(S-8)

Description of the Inclusions. The story of the last melt
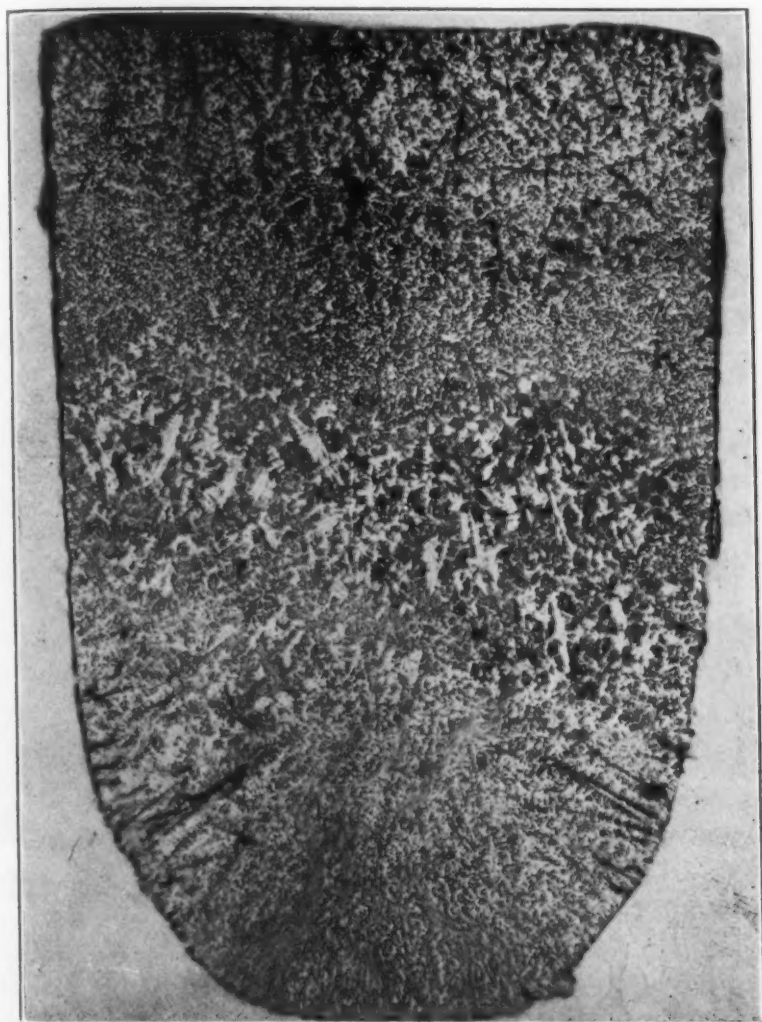
The Sulphide Melt S-8.   Fig. 82—Reproduction of the Sulphur Print. $\times$ 3½.

(S-8) is told by the sulphur print reproduced in Fig. 82.   Except for the dark MnS dendrites the print exhibits the confused structure typical for the uniform mixture of metal and of sulphide. We expect to find the pseudo-eutectic structure throughout the entire melt and we do.   This eutectic here is especially fine—a magnification of $\times$ 500 generally being necessary to bring it out, instead of $\times$ 100 as in the cases described before (Fig. 84).   In the presence of so large an excess of manganese as is available in the melt under discussion but very little FeS can form and alloy itself with the manganese sulphide.   The melting point of this FeS-poor sulphide will, therefore, be relatively high, and it is quite possible that it
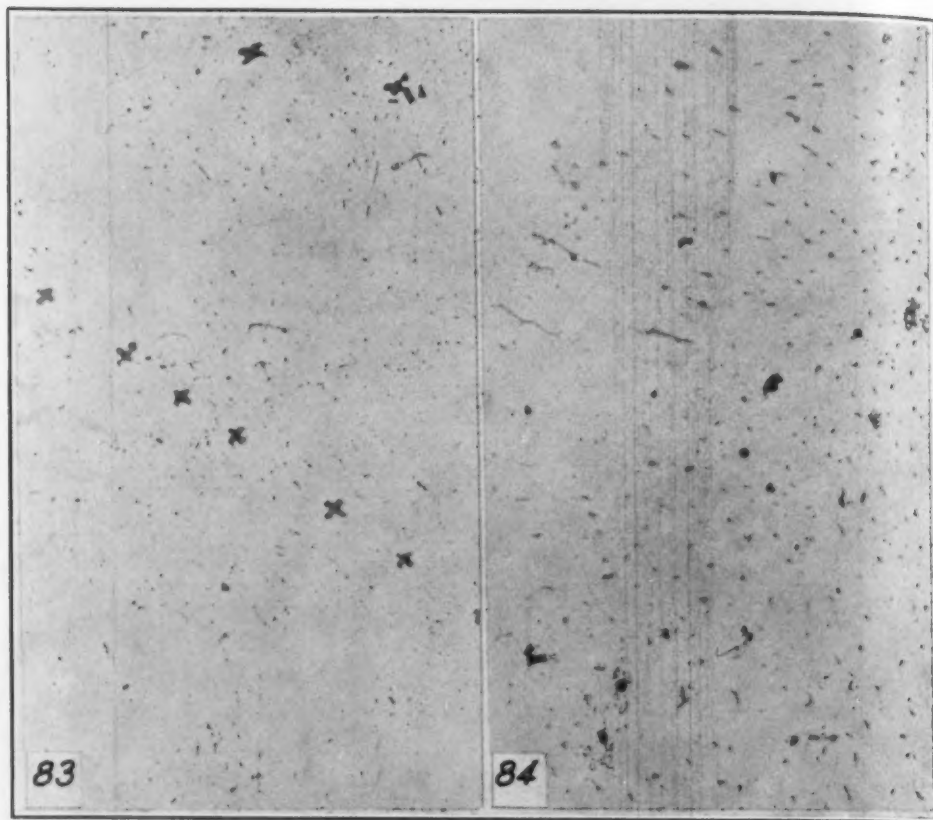
The Sulphide Melt S-8.   Fig. 83—Section Through a Set of Branches of an MnS Dendrite.   × 100.   Fig. 84—The Extremely Fine Dot Structure Formed in the Presence of a Large Excess of Manganese.   × 500.

was precipitated in the form of a cloud of fine particles already in the liquid metal, most probably at a time when the metal already had acquired a viscosity which prevented the rising toward the surface of these particles.

It is significant, perhaps, in this connection, that the finest particles were found at the bottom of the ingot.

A few sulphide dendrites are seen to be located along the ingot walls near the bottom. This in no way contradicts the conclusions drawn about the formation at the top and the floating to the top of a melt of such dendrites. The manganese, in the present melt, was charged at the bottom of the container; the bulk of it is, nevertheless, concentrated at the top. The dendrites at the bottom walls, just referred to, suggest by their position that they were held in place by the walls of the crucible (or by the metal which solidified

near the cooling walls). Fig. 83 illustrates typical cross sections of MnS dendrite branches.

THE IRON-MANGANESE-SULPHUR SYSTEM

The System FeS-MnS. The first FeS-MnS equilibrium diagram was worked out by G. Röhl (37). It is reproduced, in its original form, on Fig. 85. According to Röhl a compound of the
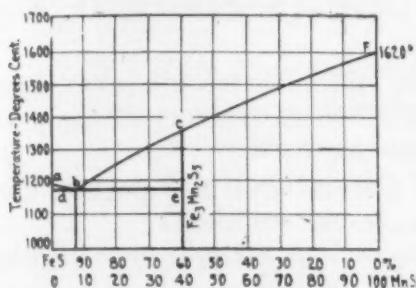
Fig. 85—The First FeS-MnS Equilibrium Diagram as Worked Out by G. Röhl.
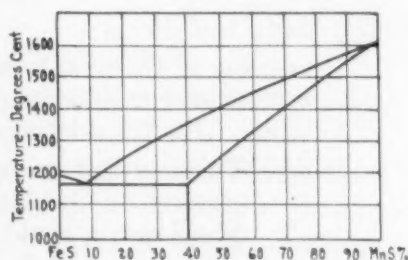
Fig. 86—The Corrected FeS-MnS Diagram as Given by McCance.

composition 60 per cent FeS and 40 per cent MnS, corresponding to the formula $Fe_3Mn_2S_5$, is formed. Unlimited solubility exists between this compound and excess manganese sulphide. On the other hand, if iron sulphide is in excess, a eutectic of FeS (or of Fe-FeS) and $Fe_3Mn_2S_5$ appears (7 per cent MnS, 93 per cent FeS). As was correctly pointed out by McCance, the thermal and microscopical data of Röhl imply in no way the existence of the compound just referred to. The point corresponding to a composition of 40 per cent MnS and 60 per cent FeS merely indicates the limit of solid solubility of MnS in FeS. The corrected diagram, as given by McCance (41), is reproduced in Fig. 86, and is in good accord with the findings of the author. The high melting point of manganese sulphide was verified and the existence of solid solutions between FeS and MnS substantiated. It was further found that there exists a continuous series of solid solutions beginning with pure MnS and ending with a limiting solution of a composition fairly rich in FeS. The yellow sulphide of the author should correspond to the eutectic with 7 per cent MnS shown in Röhl's diagram. Having found no conclusive evidence of a eutectic structure the writer is inclined to believe the inclusions to be pure FeS. The components of this eutectic, it appears, have a decided tendency to "ball up" or segregate, and it is not unlikely that some of

the duplex inclusions which showed a pale gray center with a yellow rim had originally a eutectic structure.

Röhl's diagram does not account for changes subsequent to solidification of the sulphides; unmistakable evidences of such changes were, however, observed by the writer. These latter observations appear to be verified by a recent paper on the FeS-MnS system by Zen'ichi Shibata (48) to which the writer unfortunately had no access. An abstract of the paper as prepared by Dr. Kotara Honda reads as follows:

"By means of thermal analyses and miscroscopic investigation, the author determined the equilibrium diagram of the system FeS-MnS. He found the following facts:

(1) The melting point of FeS is 1163 ± 2 degrees Cent.; and of MnS 1610 ± 3 degrees Cent.

(2) The author could not confirm the existence of a compound $Fe_3Mn_2S_5$ found by Röhl.

(3) FeS and MnS form limited solid solutions alpha and beta with each other.

(4) Alpha solid solution dissolves 2 per cent MnS at the eutectic point, but almost none at room temperature. On the other hand, beta solid solution dissolves 75 per cent of FeS at the eutectic point, but only 24 per cent at room temperature."

The Reversibility of the Reaction FeS + Mn = MnS + Fe appears to be established without reasonable doubt. The melts of the author were prepared in vacuo and no oxygen or oxide which is held to be responsible for the "apparent" reversibility of the reaction was present in them. None the less it proved impossible, except in the presence of a most drastic excess of manganese, to obtain inclusions entirely free from the yellow sulphide. The amount of the yellow sulphide was, further, distinctly governed by the amount of manganese present. In other words, a definite equilibrium between the iron, the manganese and the sulphides does exist in the melt. This shows that the reaction is a balanced one, and this in turn implies that MnS must, to a certain extent, be soluble in molten iron. For, FeS and manganese are known to be soluble in iron; hence MnS must be present in solution if it influences the equilibrium. The extent of this solubility is of course very small, as is well known.

5. *Summary*

The outstanding facts about sulphide inclusions may be summarized as follows:

I. Sources. Sulphides form in the presence of sulphur which is introduced into the metal primarily with the pig iron and the scrap. Producer gas is also a source of sulphur. (51-52).

II. Formation and Constitution. Iron sulphide is soluble in all proportions in molten iron and essentially insoluble in solid iron. It forms a eutectic with iron of a composition 85 per cent FeS, 15 per cent iron.

Solidification of sulphide-bearing iron will, therefore, take place as follows:

(a) Pure iron dendrites form and grow

(b) The remaining liquid surrounding the dendrites becomes richer and richer in sulphide

(c) This liquid finally attains the eutectic composition and solidifies (at about 980 degrees Cent.) in the dendritic fillings, yielding the cell wall or enveloping membrane type of sulphide inclusions. These inclusions appear to be pure FeS, the eutectic proportion of iron uniting with the neighboring iron.

(d) Such sulphide as was retained in solution by the solidifying "pure" iron will be precipitated on further cooling. Such precipitated sulphide will appear in the form of very fine globules.

Pure iron sulphide generally forms only in the absence of other sulphide-forming elements, although individual pure FeS inclusions will be found even in the presence of such elements.

In the presence of manganese a considerable proportion of sulphide is converted (in the liquid melt) into manganese sulphide, or rather a solution of iron sulphide and manganese sulphide, the composition of which is a function of the relative concentration of manganese.

Manganese sulphide and mixed sulphide rich in MnS is practically insoluble in liquid iron and will, therefore, crystallize out and float to the top of the melt if opportunity for this be given. Pure MnS can form only in the presence of a considerable excess of manganese and inclusions of pure MnS only when the latter was prevented from reaching the slag.

The solubility in iron of the remaining sulphide is a function of the FeS content of the sulphide. The higher the FeS content the more sulphide is held in solution at a given temperature and

the greater is the depression in the solidification temperature of the iron caused by such dissolved sulphide. In the presence of sufficient manganese some sulphide relatively rich in manganese will crystallize simultaneously with the first iron to crystallize forming a very fine aggregate of globular inclusions. The remaining melt will have a slightly higher relative concentration of FeS and will hence solidify at a slightly lower temperature—solidification of the metal again being accompanied by solidification of sulphide of a corresponding solidification point. Progressively crystallizing portions of the metal become thus richer and richer in relative FeS content (poorer in relative MnS content) and embrace inclusions correspondingly richer in FeS.

As the FeS content of the inclusions rises, the globules at first, become larger and then elongate into streaks. The last sulphide portions to solidify are squeezed into the dendritic fillings, and appear as cell walls just as in the case of pure FeS. These cell walls are made up here, of an aggregate of pure FeS and a limiting solid solution of FeS in MnS.

The globular inclusions are composed for the most part of solid solutions of FeS in MnS, although aggregates of pure FeS and the limiting FeS-MnS solid solution are not uncommon. Pure FeS globules are of course also met with.

In general, in the presence of a sulphide-forming element soluble in iron, sulphides of this element will form at the expense of iron sulphide, to an extent governed by the equilibrium conditions existing in the metal bath. If a sulphide thus formed is largely insoluble in the molten metal and opportunity is given for it to leave the bath, desulphurization (or at least partial desulphurization) of the bath will take place. Such sulphide as remains in solution will, in general, be precipitated on solidification of the iron, the constitution of individual inclusions, their form and location, depending on the temperature and conditions of their formation.

The higher the solidification point of these sulphides the smaller they will, in general, be and the more uniformly distributed. Sulphides which accumulate in solution in portions of the iron last to solidify will be squeezed in the inter-dendritic spaces and solidify there in the form of more or less continuous membranes.

Sulphides precipitated prior to solidification of the metal may

be retained as inclusions if they are unable to reach the slag.

III. Behavior. Ordinary heat treatment does not affect the location and form of sulphide inclusions. Migration of sulphides—to grain boundaries (or otherwise)—does not take place, many statements to this effect notwithstanding. Changes within individual inclusions do, however, take place, especially in case of duplex inclusions, where quenching, for example, may suppress the formation of a well developed eutectic, prolonged annealing result in a divorce of the constituents of the eutectic, etc. Sulphide inclusions are plastic at rolling temperatures and are elongated by hot working into streaks.

IV. Appearance. Pure iron sulphide may be described as having a pale "creamy yellow" color. It is distinctly yellowish and differs in this respect from all other inclusions found in iron.

The solid solutions of FeS in MnS have a distinct dove gray color which is generally the darker, the higher the proportion of MnS. The limiting solution of FeS in MnS is of a very pale gray color; the brilliancy of this latter solution is identical with that of pure FeS.

Pure MnS inclusions exhibit ordinarily distinct skeleton crystal outlines.

Solid solutions rich in MnS appear in the cast metal in the form of very fine globules, generally of the order of 0.002 millimeters and less. Solid solutions rich in FeS yield larger globules and elongated forms. Pure FeS appears both in the form of cell walls—often exceedingly fine—and in the form of globules.

V. Reactions. Etching in 10 per cent nitric acid leaves sulphides unchanged.

A 10 per cent chromic acid solution in water attacks MnS and solid solutions rich in MnS; fails however to effect any changes in the solid solutions poor in MnS, especially the limiting solution, and of course in FeS.

Sulphur printing for 20 seconds, using 2 per cent H_2SO_4, destroys all inclusions containing MnS in solution, and leaves FeS inclusions essentially unchanged. (A stronger H_2SO_4 solution—10 per cent for example—or repeated applications of a 4 per cent solution, destroys FeS).

Boiling sodium picrate blackens all sulphide inclusions.

Educational Section

These Articles Have Been Selected Primarily For Their Educational
And Informational Character As Distinguished From
Reports Of Investigations And Research

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part XIX[1]

By H. B. Knowlton

Abstract

This article gives a discussion of the common errors in case hardening, and their methods of prevention. Among the subjects discussed are: failure to withstand wear, spalling, cracking in hardening, cracking in grinding, breaking, distortion, and abnormal steel.

The second section of the article is devoted to the discussion of cyaniding, nitriding, and the steels for nitriding.

ERRORS IN CASE HARDENING

WHILE the case hardening method when properly carried out gives some very valuable results, it is true that there are numerous errors which appear in case hardening if the process is not properly controlled. It is not always easy to determine the causes of all of these errors and the methods of correction. In the following paragraphs it will be attempted to discuss some of the most common errors and their causes so far as known.

1. *Failure to Withstand Wear or Abrasion.* This may be due either to insufficient hardness of the case or to the condition of wear being too severe for the design of the piece. Insufficient hardness may be often proven by means of the hardness testing machines or by means of a file. Unfortunately the depth of case affects the reading of the scleroscope and the Rockwell machines,

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[1]This is the nineteenth installment of this series of articles by H. B. Knowlton. The several installments which have already appeared in TRANSACTIONS are as follows: March, June and October, 1925; January, April, May, June, August, October, December, 1926; March, May, July, September, November, 1927; January, May, July, 1928.

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to some extent. Brinell readings give low results on case hardened work as ordinary cases are not deep enough to withstand the standard Brinell load. There may be considerable variation in the carbon content in the surface layer of the case of two articles which give nearly the same hardness reading. It is probable that other things being equal the steel with the higher carbon content will give the greater resistance to wear.

It is sometimes found that pieces have worn excessively in service in spite of the fact that the carbon content, the depth of case, and the structure and the hardness have been ideal. This can only mean that the service is too severe for the piece. For example, if the teeth of a gear are too small for the load excessive wear might be expected. The points of the teeth of clash gears in automotive transmissions may be worn by continual poor shifting, no matter how good the case hardening. Obviously lack of lubrication or the presence of foreign substances such as sand, grit, etc., will cause wear.

1.A—Lack of Sufficient Hardness. Lack of sufficient hardness may be due to poor carburizing, poor quenching or poor tempering. Conditions which will cause poor carburizing are: poor steel; packing pieces against each other or against the sides of the carburizing box; packing of dust, ash, or foreign matter in the carburizing compound tightly against the steel to be carburized; the use of a weak or worn out carburizing compound; too low a carburizing temperature; decarburizing at the end of the run due to leakage of air into the carburizing box.

Poor steel will be discussed later. The other conditions mentioned may apply to all of the pieces in one carburizing load or they may apply only to a portion of them or even to certain spots on some of the pieces. For example, packing of pieces too closely together will only prevent carburizing at the points of contact; a very dusty or dirty compound may settle tightly against spots on some of the pieces only causing soft spots after hardening; a poorly mixed carburizing compound may produce good carburizing in one box but poor carburizing in another one, in fact the carburizing may vary in different portions of the same box; similarly if the temperature is not uniform in all parts of the furnace, some of the work may be heated to the proper carburizing temperature while other portions of the work may be heated too low or too high; decarburizing at the end of the run

usually affects only that portion of the work which is near the cover of the box or near a crack or hole.

It can not be said too strongly that lack of uniformity of carburizing conditions is one of the most frequent sources of trouble. Too often a pyrometer record showing the temperature of one point in the carburizing furnace is taken as a criterion for judging the temperature of the whole furnace. Variations front to back, side to side, and top to bottom are not uncommon. Boxes should stand on legs and be placed in regular rows spaced apart so that the furnace gases can circulate all around and above and beneath them. They should not be too close to the door nor the rear wall nor in the path of a flame.

1.B—Poor Quenching. One cause of poor quenching is failure to heat to the best quenching temperature. Again uniformity of heating of all pieces is necessary if they are all to attain the same degree of hardness. Other causes of poor quenching resulting in insufficient hardness, are: dumping of too many pieces in a mass in the quenching tank; insufficient speed of circulation of the quenching medium; quenching bath too hot, if water; bath either too hot or too cold, if oil. Quenching in general has been discussed more in detail in a previous chapter.

1.C—Poor Tempering. Too high a tempering temperature will cause insufficient wear hardness. As a general rule the tempering temperature should be very low as the only objective of tempering should be to relieve strains. Toughness should be produced by proper grain size and structure of both case and core rather than by high tempering temperatures. In this respect the heat treatment of carburized articles differs somewhat from that of medium carbon steel parts. A tempering temperature of 325 degrees Fahr. is frequently sufficient, and 400 degrees Fahr. should be the maximum in most cases. There may be instances where temperatures of 500 to 600 degrees Fahr. are advisable, but it must be remembered that raising the tempering temperature probably lowers the resistance to wear more than might be thought from the hardness readings.

1.D—Grinding Through the Case. It seems ridiculously superfluous to say that if the case is all removed by grinding the piece will be soft, and yet this is one of the most common causes of softness in finished pieces. Frequently a great deal more stock is removed from one side than the other, with the result that one

side is hard and the other soft. Many disputes have been raised over the question of how much stock should be left for grinding after hardening. From the heat treater's standpoint the less stock left the better. No general rule can be given which will apply to all cases. Obviously there must be enough stock left to assure that the piece will "clean up." On the other hand if it is necessary to leave 0.030 inches or more in order to assure that the piece will clean up it is evident that nearly 0.030 inches will be removed from one side. It is difficult to produce a case which is as hard 0.030 inches below the surface as it is on the surface unless the case is extremely deep (more than 0.065 inches). Such deep cases are not always desirable. Closer cooperation between the machining and the heat treating departments will frequently solve these problems.

2. *Spalling.* Spalling or chipping off of the surface of the case is said to be due to four causes: presence of envelopes of free cementite in the surface layer; exfoliation; too thin a case and too high a quenching temperature. The presence of envelopes of free cementite in the hardened part may be prevented by decreasing carburizing action so that the maximum carbon content produced is not over 0.90 per cent, or by quenching directly from the carburizing box. The envelopes formed during slow cooling from the carburizing temperature may be broken up by reheating to a temperature above the Acm line and quenching followed by a second reheating to the proper refining temperature and quenching. Where maximum resistance to wear is desirable, either of the last two methods is probably preferable to holding the carbon content below 0.90 per cent, as the higher the carbon content the greater should be the resistance to wear, providing the cementite is in the proper condition.

It is often not appreciated that spalling may be due to lack of sufficient depth of case. As examples of this the writer has had occasion to examine two automotive transmissions in each of which one of the gears was badly spalled while the gear with which it was running in mesh was not spalled. In both instances it was the larger gear which showed the spalling. This seemed peculiar as the smaller gear makes more revolutions and, consequently, receives more wear than the larger gear with which it meshes. Microscopic examination of sections cut through the teeth of the two gears showed that the smaller gear had a much

deeper case than the larger gear. It happened also that there were some envelopes of cementite present in the case of the smaller gear and none in the larger gear. Yet it was the larger gear which spalled. The explanation seems to be that the thinner case was not strong enough to withstand the tooth pressure. The result was a tendency to bend the surface of the tooth back and forth as the load was applied and released. No matter how good the hardened structure it could not withstand this action.

It has been suggested that spalling is a fatigue failure, due to some such action as just described. The gradation zone between the case and the core is said to be the weakest towards fatigue. Consequently if this zone is near enough the surface to receive a high stress it will be subject to fatigue failure. This may be the explanation of why the gears with the deeper case did not spall.

Another cause of spalling is too high a temperature for the final quench. A direct quench from a carburizing temperature of 1700 degrees Fahr. or above will produce a very coarse brittle case which will spall very easily. The case may be refined by reheating to the proper temperature and quenching. Some steels suffer more than others from grain growth when heated to high temperatures. A 5 per cent nickel steel may be heated high enough to refine the core without producing a coarse grained case, but plain carbon steels and some of the other alloy steels can not.

3. *Cracking.* Quenching cracks occur in case hardening for the same reasons as in other types of hardening. Nonuniform cooling of thick and thin sections is one of the common causes. Screw threads are particularly subject to hardening cracks. This may often be prevented by protecting the threads from coming into direct contact with the quenching medium. External threads may be covered with clay or with metal caps before heating for hardening. Similarly plugs may be screwed into threaded holes. In general it is well to fill all small holes which do not need to be hard. When the threads appear at one end of the piece it is possible to quench so as to leave the threaded end projecting above the level of the quenching liquid. In general, oil quenching is less dangerous than water quenching but sometimes does not produce sufficient hardness. Of course, the methods suggested of preventing cracking involves additional labor and should only be resorted to when necessary.

Case hardened articles are frequently found to be cracked after grinding. As a general rule the grinders place all the blame on the hardener while the latter insists that the grinding is responsible. It is probable that either poor hardening or poor grinding may result in grinding cracks. If the hardener leaves the case in an extremely brittle coarse-grained condition it may be expected that grinding cracks will occur. On the other hand the best hardened piece may be cracked by improper grinding. The cracking is due to the local heat produced by grinding. This tends to expand the surface of the steel without expanding the whole piece. As the surface of a properly case hardened piece is file hard it will not stand much expansion without cracking. The remedy lies in varying the grinding conditions so as to produce less heat. This may mean a softer wheel, a lower wheel speed or a change in the feed. Whenever the ground piece shows a "temper color", even a faint straw, it is safe to assume that it has been unduly heated during grinding. Sometimes these colors appear in the first stages of the grinding operation and are removed by the time the piece is finished. The fact that the finished piece is not discolored is no proof that it was not overheated at any stage of the grinding. Poor grinding may cause soft spots as well as cracks, as the heating produced by such grinding acts as a high tempering treatment.

4. Breaking of the Entire Piece. A failure involving breaking of an entire piece or an entire section such as a gear tooth may be due to any of the following causes: case too deep, case brittle, core not properly refined, wrong kind of steel, or too light a design. Pieces having thin sections are the most likely to fail due to too thick cases, since thick cases mean that there is not sufficient metal in the cores to give the necessary toughness. Pieces which are subjected to bending loads fail by fatigue, the failure appearing first in the surface layers and gradually spreading through the piece. Consequently, if the case is very brittle, it is very easy for a fatigue failure to start at the surface no matter how strong and tough the core may be. On the other hand if the core is not properly heated it will not give the piece sufficient strength and toughness. The core should be treated so that it is fine-grained. Unfortunately the treatment that is the best for the core is not always the best for the case and it is sometimes necessary to give a compromise treatment. When failures are due to insuf-

ficient strength it may be advisable to change to a steel which will yield a higher strength. Lastly, failure may be due to the design being too light. The answer to this trouble is obvious.

5. *Distortion.* In the manufacture of case hardened gears warping and distortion constitute one of the biggest problems. It is generally conceded that there is likely to be a change in some dimension during case hardening. Frequently the outside diameter of the gear will contract while the hole will become larger. A contraction in diameter of the gear means that the space between teeth is decreased. Consequently, when the pitch diameter is measured over pins placed between the teeth, it appears that the pitch diameter has increased. What really has happened is that the gear has contracted bringing the teeth slightly closer together, forcing the pins further out. It is sometimes claimed that individual teeth distort. It is probable that the distortion of individual teeth is too slight to be measured by any ordinary means. Considering that the change in diameter of a 6-inch gear is probably about 0.003 inch, a proportional change in the thickness of the average gear tooth would be about 0.0001 inch.

Not all of the dimensional errors found in finished gears are truly chargeable to the heat treating, although it is usually the heat treater who gets the entire blame. The writer has had occasion to study the dimensional errors of gears in several different plants and has frequently found that the major portion of the errors were traceable to the machining operations, while the heat treating only added 0.002 to 0.004 inch on the largest dimension. This was true in spite of the fact that a rigid 100 per cent inspection was given all machined gears before heat treating. The errors in the finished gear are often a gradual accumulation of very small errors in different operations. A complete discussion of errors would require many pages. It is only possible here to give a word of caution against assuming that all of the errors or even the major portion of them are due to heat treating.

On the other hand, the heat treater should not be relieved of the responsibility of putting the gears through with the minimum amount of distortion. Uniform heating, control of the quenching temperature and uniform quenching, will all help. Some have found that the hump and the dilatometer methods of heat treating are very valuable. At least one metallurgist has made use

of the fact that the critical point on cooling is much lower than the critical point on heating in order to decrease the severity of the quench and the amount of distortion. The gears are heated in melted lead or salt to the correct temperature (above the critical point on heating) and then are transferred to another salt bath at a temperature just above the critical point on cooling (about 1200 degrees Fahr. for some kinds of steel). From this bath they are quenched in water or oil. The gears come out just as hard as if they were quenched from the original temperature and the distortion is reported as being much less. This is a violation of the old rule to always quench on a rising temperature, but it is perfectly satisfactory from a theoretical standpoint and has been reported as giving very good results.

Abnormal Steel

The discussion of normal and abnormal steel and their relation to case hardening is approached with considerable reluctance. There are yet many differences of opinion on this subject, and many pages have been written pro and con. Only a brief summary can be given herein.

Several years ago McQuaid and Ehn attempted to determine the cause of soft spots and other troubles in their case hardened work. They knew that steel from certain heats gave soft spots after case hardening and others did not and yet there seemed to be no difference between the chemical analysis or the microstructure of the good and the bad lots of steel. They discovered there was a decided difference between the microstructure of the two kinds of steel after carburizing at a certain temperature and cooling slowly. The type of structure which appeared in the steel that hardened properly at ordinary temperatures, they termed "normal' while the structure of the steel which gave trouble in hardening, they called "abnormal." Some think that the terms "normal" and "abnormal" were unhappily chosen. There are varying degrees of normality and abnormality and no sharp dividing line between the normal and the abnormal. There is a difference of opinion as to just what structure is the best.

The accompanying illustrations show the structure of two steels after carburizing at the same temperature and cooling slowly. The magnification is the same in both cases. The depth
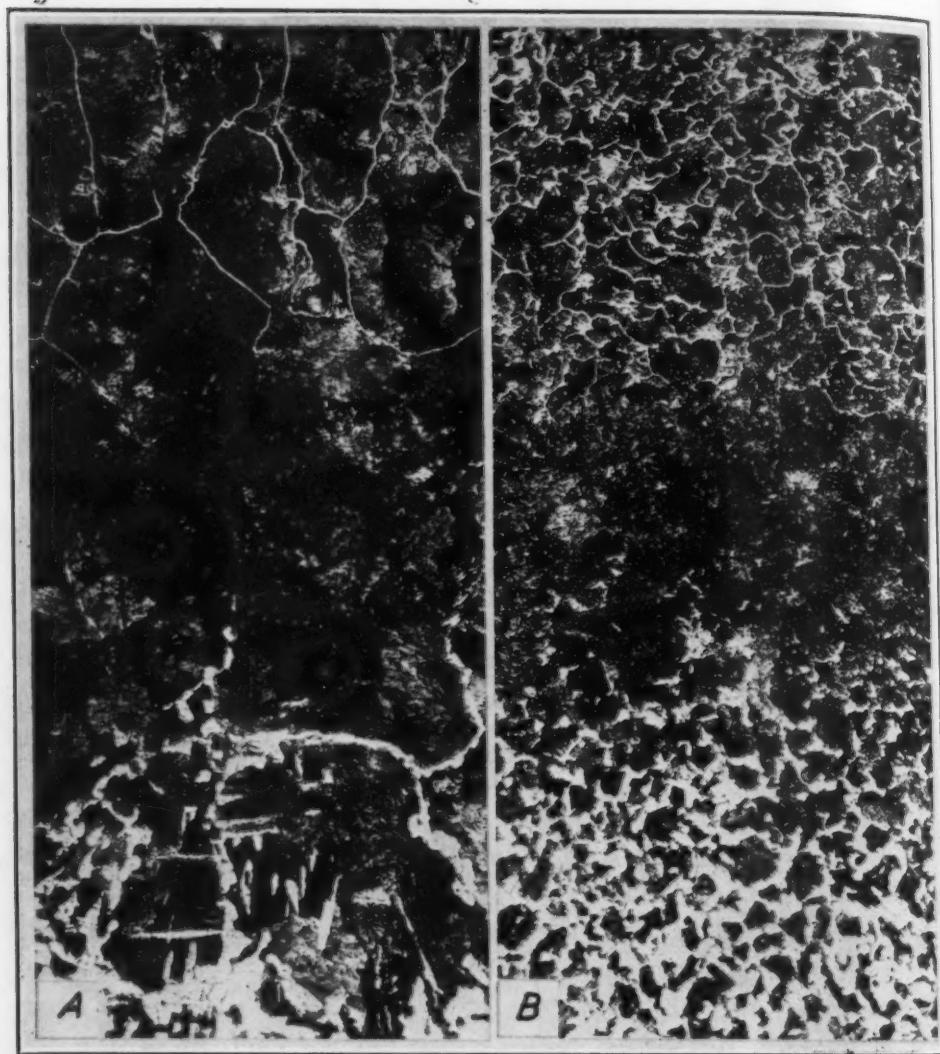
Fig. 1A—Photomicrograph Showing the Structure of the Three Zones of the Case of a Normal Steel.   × 150.   Fig. 1B—Photomicrograph Showing the Structure of the Three Zones of the Case of an Abnormal Steel   × 150.   Courtesy R. G. Guthrie.

of each of the three zones of the case and probably the per cent of carbon at the surface are approximately the same in both cases. The two steels probably analyzed the same and appeared the same under the microscope before carburizing and yet there is a very apparent difference in the structures after carburizing.

Fig. 1A represents the type of structure described by McQuaid and Ehn as normal, while Fig. 1B represents an abnormal steel. The most striking difference is the variation in grain size.   The networks of ferrite and cementite in the hypereutectoid and hypo-

eutectoid zones of Fig. 1A are quite large. These represent about the normal grain size for a plain carbon steel when carburized at 1700 degrees Fahr. The network in Fig. 1B, although produced by carburizing at the same temperature, are much smaller. Evidently this steel did not suffer from so much grain growth on being heated to the carburizing temperature.

There is another difference which is not quite so apparent at first glance. The structure in Fig. 1A is much sharper. The hypereutectoid zone in Fig. 1B appears somewhat "fuzzy." It contains some small particles of free ferrite in addition to the cementite and pearlite which are normally expected in the hypereutectoid zone. The grain size in the hypoeutectoid zone is also much smaller. It is sometimes reported that there is a greater variation in the size of individual grains in an abnormal steel than in a normal steel.

The fact that there is both free ferrite and free cementite present in the hypereutectoid zone of an abnormal steel is more clearly apparent in Figs. 2B and 3 which show the structures under higher magnifications. In both of these illustrations it will be seen that the cementite network appears in the middle of larger bands of ferrite. This was considered to be an abnormal condition and such a steel was called abnormal.

The original investigators considered that the abnormal structure was due to the presence of oxides in the steel in such a finely divided form that they could not be seen under the microscope. They supported their contention by producing a series of steels having varying degrees of deoxidation from no deoxidation to nearly complete deoxidation. After carburizing they showed varying degrees of normality and abnormality depending upon the degree of deoxidation. More recently Harder and his associates have brought out quantitative proof that abnormal steel contains a foreign substance (probably oxides) not present in normal steel.

McQuaid and Ehn found that the normal steels would harden uniformly while the abnormal steels were likely to have soft spots after hardening; also that abnormal steels might require higher hardening temperatures than normal steels. The normality of the steel evidently played an important role in commercial hardening.

This led to the establishing of a routine test on incoming
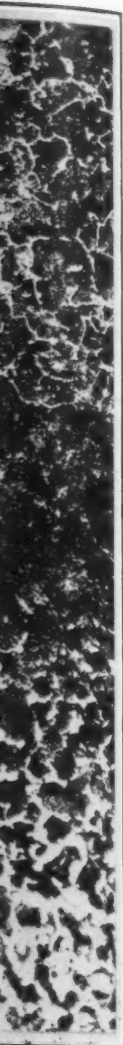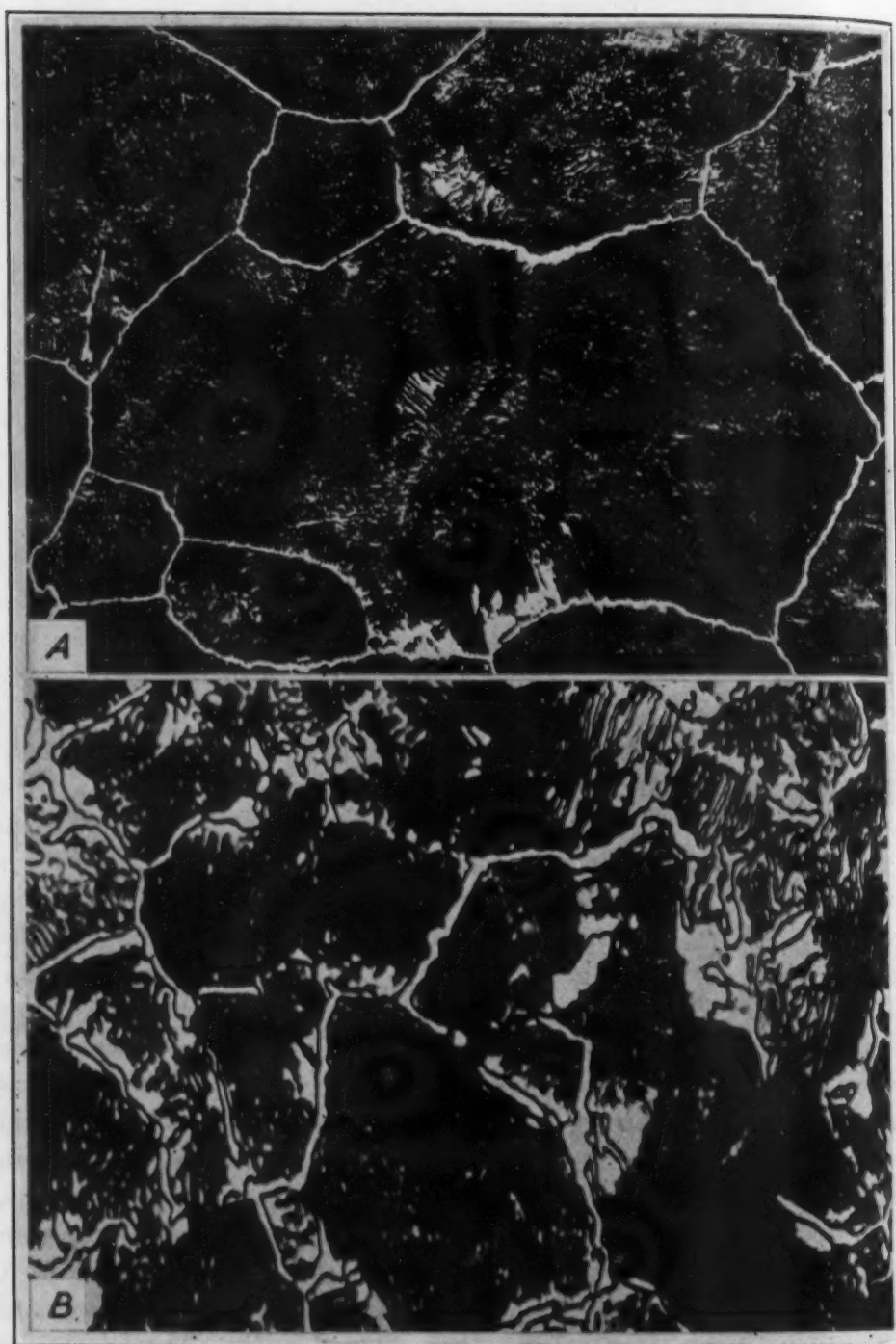
Fig. 2A—Photomicrograph Showing Hypereutectoid Zone of a Normal Steel.   × 425.
Fig. 2B—Photomicrograph Showing Hypereutectoid Zone of an Abnormal Steel.   × 425.
Courtesy R. G. Guthrie.

Fig. 3—Photomicrograph of an Abnormal High Carbon Steel Annealed.   × 500.   Courtesy R. G. Guthrie.

carburizing steels which is now known as the McQuaid-Ehn test. Samples of steel are carburized at a given temperature and are allowed to cool slowly. Sections of the carburized and slowly cooled specimens are polished, etched and examined under the microscope. The grain size can be measured by counting the number of grains per square inch at a given magnification.

Unfortunately it is not possible to divide all steels into two classes, a coarse-grained or normal steel, and a fine-grained or abnormal steel. Some of the steel companies have made up standard reference charts showing 9 or 10 different grain sizes varying from very coarse to very fine. It is possible for the customer to order a steel of the grain size he thinks is the best for his purpose.

It might seem from the foregoing that the coarsest grain steel would be the most normal and would harden the best and, consequently, would be the most desirable. However, this has not been found to be the case. Some of the alloy carburizing steels are naturally very fine-grained and yet they harden better and more uniformly than the normal plain carbon steels. On the

basis of the grain size test they might be classed as extremely ab-
normal steels but for practical use they are very desirable. The
question may well be raised as to whether they should be called ab-
normal.

There are some very obvious advantages for the fine-grained
alloy steels, providing the fine grain is not accompanied with the
trouble with soft spots first reported in the case of the fine-grained
carbon steels. A steel which is fine-grained even after cooling
from the carburizing temperature will not have a coarse-grained
case after quenching from a temperature high enough to refine
the core. It should be much tougher than one which suffers
readily from grain growth if heated above the lowest hardening
temperature for the case.

While there have been many discussions over the interpre-
tation of the McQuaid-Ehn test, it seems to the writer that the
test has brought out some very valuable information and that it
will be used more in the future than it is even at the present
time. At least one large manufacturer is now applying this test
not only to carburizing steels but to all grades of steel. Some
of the steel manufacturers say that this test has opened up a
large field for study. Whether a fine-grained or a coarse-grained
steel should be specified probably depends upon the kind of steel
and the purpose for which it is to be used.

CYANIDE HARDENING

Before leaving the subject of case hardening it may be well to
make some mention of methods which do not involve carburizing
with solid carburizers or directly with gas. The most common of
these is cyanide hardening.

The simplest and probably the best method of cyanide hard-
ening consists in heating the steel in a bath of melted cyanide to a
temperature of about 1500 degrees Fahr. for a few minutes to a
half hour. The steel is removed from the cyanide bath and
quenched directly in water or oil. It may afterwards be tem-
pered although frequently it is not. This method produces a
very hard case which is usually only a few thousandths thick.
It is very valuable for parts which receive only a small amount
of wear. For example small screws and nuts are probably best
treated in cyanide. If these parts received a deep case they would

be too brittle. The skin hardness is sufficient. Cyanide hardening is quick and inexpensive. No scaling is produced by this method. The melted cyanide adheres to the surface of the steel while it is being transferred from the bath to the quenching tank thus protecting it from the scaling action of the air.

For years the blacksmiths have used powdered cyanide or ferrocyanide in some form for surface hardening. The steel is heated in the forge to a bright red or orange and then is removed and sprinkled with powdered cyanide. It is then returned to the forge and heated again. The cyanide melts and flows around the steel. This process is usually repeated several times before the steel is quenched. This is only a crude method of heating in melted cyanide, but one which is valuable when no other means is at hand.

A few years ago pure potassium cyanide was used but at the present time sodium cyanide mixed with other chemicals is frequently employed with apparently as good results. The latter mixture does not produce as many fumes and consequently is not as objectionable to the workman.

In principle, cyanide hardening involves gas carburizing. Cyanide contains both carbon and nitrogen. It is claimed that when it is heated it decomposes to some extent giving off a gas which yields both carbon and nitrogen to the steel. Both have a hardening action. It is claimed by some that the nitrogen makes the steel more brittle.

Tool steel and carburized steels are also sometimes hardened in cyanide. While this method eliminates the scale it may be questionable. The cyanide produces a skin hardness, but this skin hardness is no assurance that the steel has been properly hardened all the way through.

NITRIDING

A new method of surface hardening which does not involve carburizing at all consists in nitriding (adding nitrogen) a certain kind of alloy steel. This method is covered by a German patent and has been employed in this country for a very short time. Table I shows the typical chemical composition of three classes of steel used for nitriding.

These steels may be forged, annealed, and heat treated, the

Table I
Typical Analyses of Steels for Nitriding

	Grade A	Grade D	Grade C	Grade G	Grade H
Carbon	0.45	0.32	0.10	0.36	0.23
Manganese .	0.60	0.60	0.60	0.51	0.51
Silicon	0.25	0.25	0.25	0.27	0.20
Aluminum ..	1.00	1.00	1.00	1.23	1.24
Chromium ..	1.60	1.70	1.65	1.49	1.58
Nickel	None	1.80	None	None	None
Sulphur	0.020	0.020	0.020	0.010	0.011
Phosphorus .	0.020	0.020	0.020	0.013	0.011
Molybdenum				0.18	0.20

same as other alloy steels. Grades A, D, and G are quenched in oil from 1650 degrees Fahr. and grade C from 1700, and grade H from 1750 degrees Fahr. They may be tempered from 800 to 1400 degrees Fahr. as required to produce the desired physical properties. Table II shows the physical properties which it is claimed will be produced by quenching the steels from the temperatures given above and tempering at 1000 degrees Fahr.

It is recommended that these steels be heat treated and finish machined before nitriding. The nitriding process consists in heating in a current of gaseous ammonia at a temperature of about 875 degrees Fahr. for a period of 2 to 90 hours depending upon the depth of nitride case desired. For a case $\frac{1}{32}$ inch deep

Table II
Physical Properties of Steels for Nitriding after Quenching in Oil and Tempering at 1000 Degrees Fahr.

	Grade A	Grade D	Grade C	Grade G	Grade H
Yield Point	171,750	149,500	47,800	158,500	133,300
Tensile Strength	190,750	168,500	77,000	182,500	160,000
Elongation in 2 Inches......	13.0	14.0	30.5	15.0	17.0
Reduction of Area	40.0	45.0	69.5	50.0	54.0
Charpy Foot Pounds	12.0	14.0	61.5	35.2	30.1
Brinell Hardness	390	365	170	363	340

90 hours are required. No quench is required after nitriding.

Numerous advantages are claimed for this process. The hardness of a nitrided case $\frac{1}{32}$ inch deep as determined by the Herbert pendulum tester converted into Brinell hardness is said to be about 900 while that of a case hardened chromium-vana-

dium steel is about 700 to 750. Plug gages made of the special alloy steel nitrided are reported to have extremely long life. As the temperature of nitriding is low and there is no quench after nitriding, it is claimed that distortion is entirely eliminated. However, a 1-inch round bar will grow about 0.0001 inch. Allowance for this growth should be made in machining.

As the nitriding temperature is below the customary tempering temperature the nitriding treatment does not affect the physical properties of the previously heat treated core. Consequently, cores with very high physical properties can be produced. It is also claimed that nitride cases are resistant to rust and corrosion and that they do not loose their hardness when heated at temperatures up to 800 degrees Fahr.

It is also claimed by the manufacturers of the special steels described that the beneficial results of nitriding described are only produced when the process is applied to steels of the special analysis. The aluminum content is said to be one of the most important factors. It has also been stated that nitriding at temperatures above 1075 degrees Fahr. will produce brittleness while nitriding at 875 degrees Fahr. does not.

The nitriding process applied to these steels seems to offer some possibilities. As the present writer has only begun to experiment with this process, the foregoing discussion is based entirely upon the statements of the makers of the steels for nitriding.

REFERENCES

Abnormal Steels: American Society Steel Treating, General Index 1920-26, also A. S. S. T. TRANSACTIONS, June 1928.

Nitriding and Nitralloy: Pamphlets published by Ludlum Steel Co.

ACKNOWLEDGMENT

Comment and Discussion

Papers and Articles Presented Before the Society and Published in
Transactions Are Open to Comment and Discussion in This Column

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DISCUSSION OF PAPER BY E. C. BAIN ENTITLED "X-RAYS AND CONSTITUENTS OF STAINLESS STEEL"

BY JEROME STRAUSS[2]

MR. Bain has again contributed experiments and deductions to help clarify our understanding of the high-chromium steels. However, in Item 3 of the section devoted to the theory of the corrosion resistance of these alloys, the degree of immunity to attack is described, as related solely to the proportion of chromium in solid solution; the carbides being described as "unattacked, inert particles." This is more mildly repeated in the summary. It is true that they are unattacked but it appears unlikely that they are inert. In fact the author so states in the first sentence of the last paragraph of the summary.

The explanation offered, namely "lessening the path of electrolytic current flow," appears inadequate. Also, it is probable that this corrosion by local electrolysis is not of minor importance but equally as influential as that resulting from the proportion of chromium in solution.

It will be observed that in the author's data, the higher the hardening temperature (within limits), the higher the tempering temperature required for decrease in the hardness resulting from quenching—presumably initiation of carbide precipitation is less readily accomplished as the quenching temperature rises. Also in each instance, the maximum corrodibility occurs after a tempering temperature slightly higher than that at which softening begins. This latter fact was recorded by the writer in a paper by himself and J. W. Talley before the American Society for Testing Materials, in 1924; the variation in precipitation temperature was not so marked in those experiments. But, assuming that when softening begins, practically all of the carbide is precipitated in a finely dispersed form and that further softening is by coalescence, it appears more likely that the explanation is one of surface action; when precipitation begins the particles are too small to effect electrolytic solution of the chromium-iron matrix and after high temperature tempering, the ratio of their surface to volume is too low to produce great influence. But, at some intermediate particle size the corrosion reaction proceeds at a maximum rate. This explanation was hinted at in the above paper (Part II, page 246). The results upon which that comment was based have since been frequently repeated upon other melts of similar compositions. It is believed that, had the author carried his tests to higher tempering temperatures,

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[1]E. C. Bain, "X-rays and the Constituents of Stainless Steel," TRANSACTIONS, American Society for Steel Treating, Vol. XIV, July, 1928, page 27.

[2]The author of this discussion is associated with the Vanadium Corporation of America, Bridgeville, Pa., formerly material engineer, U. S. Naval Gun Factory, Washington, D. C.

maximum values of corrosion for the higher quenching temperatures would have been secured in the vicinity of 1110 degrees Fahr. (600 degrees Cent.)

E. C. Bain's Reply: I am grateful for the able discussion offered by Jerome Strauss. Mr. Strauss has made such fundamental contributions to our knowledge of stainless steel that any suggestions he may make merit serious consideration. In this case, our attention would be well called to the question of the function of carbide particles in corrosion, even though it had not been pointed out by such an authority as Mr. Strauss.

With the state of our knowledge being as limited as it is at the present time, there is certainly ample room for a diversity of opinion regarding the rôle played by carbide particles in the corrosion of high-chromium alloys. I think we are all in agreement that carbide particles would always tend to act as cathode regions under normal conditions of simple acid corrosion; hydrogen would be evolved upon such particles. In the absence of oxygen I should imagine there would be no question that the presence of these carbide particles with low solution pressure would actually stimulate chemical attack, but in the case of the iron-chromium alloys in an oxidizing environment, a genuine protection is offered by the very first oxidation products. Theoretically, this sort of protection would not be decreased by the presence of more noble or cathodic particles; hence, it is in the simple acid attack and not in the oxidizing part of the reaction that the cathode particles play their part. It is, therefore, my opinion that if a solid solution of chromium in iron has the proper composition to be protected by the oxygen reaction, then the presence or absence of carbide particles makes no difference, as in the case of 25 per cent chromium alloys carrying 0.35 per cent carbon and corresponding carbides. I am not entirely in agreement as to the suggestion that a carbide particle could ever be unable to act as a cathodic surface due wholly to its smallness.

To test this assumption out in a preliminary way, I prepared some samples of stainless steel in a condition in which they were barely unattacked by dilute nitric acid. I then introduced artificially a number of very effective cathodic particles. To accomplish this, gold filings were pressed onto the surface of a slightly roughened sheet. The sheet so prepared did not suffer attack and under the microscope did not indicate that any local action had taken place immediately around the gold particles. The reasoning in this experiment was that gold particles would be at least as effective as carbide particles in stimulating reaction if the ordinary mode of electrolytic attack was operating. Personally, I do not regard the point in question as absolutely settled, but I have formed an opinion with some reservations, since I believe that the present evidence weighs more heavily against the theory of carbide particle activity than for it. I realize too that my opinion is in disagreement with that of Brearley who has spent many years in the study of stainless alloys.

Another point which is enlightening, but not wholly conclusive, is that the carbide in stainless steel contains about 60 per cent chromium. If one estimates the probable volume of the carbides and then computes the amount of chromium tied up in this form under various conditions of heat treatment, he finds that the chromium in solid solution in the alloy develops resistance to attack in fair agreement with the hypothesis.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,671,810, Annealing Apparatus, Edward G. Caughey, of Sewickley, Pennsylvania.

This patent describes an annealing apparatus for the annealing of strip steel in continuous length. The annealing chamber 1 is made of such length that the annealing may be effected by a single passage of the material therethrough. The material is delivered from a reel 2 to pinch rolls 3 and then passes through the troughs 7 with the side walls exposed
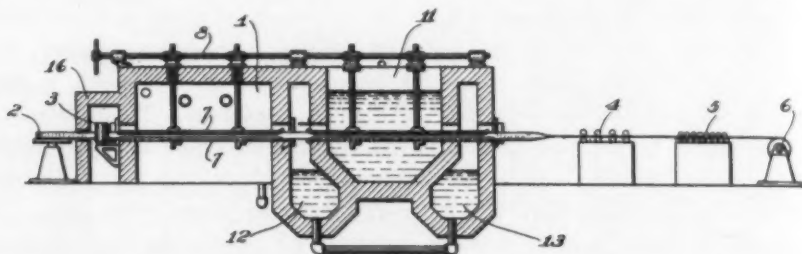
to the annealing conditions within the chamber 1, from which it passes into a cooling and coating tank 11 and thence through a cleaning machine 4 and a leveling machine 5 to the rewinding wheel 6. The cooling liquid in the chamber 11 is circulated by a suitable pump and a slight amount thereof overflows into the pits 12 and 13 from which it is recirculated into the chamber 11.

1,671,870, Method of Treating Manganese Steel, Van Cortright Mekeel, of High Bridge, New Jersey, Assignor to Taylor-Wharton Iron and Steel Company, of High Bridge, New Jersey, a corporation of New Jersey.

This patent describes a method of imparting greater strength and wear-resisting properties to manganese steel without impairing the toughness of the metal by case hardening or case boronizing the piece during the regular heat treatment and quenching the articles under conditions which reduce to a minimum the exposure to air.

1,672,446, Production of Rimmed Steel Ingots, Arthur Tregoning Cape, of Massillon, Ohio, Assignor, by mesne assignments, to Midwest Metallurgical Corporation, of New York, N. Y., a corporation of Delaware.

This patent relates to the production of rimmed or effervescing steel ingots. The object is to provide a more solid rimmed ingot, freer from blowholes and "black butts". The production of satisfactory rimmed ingots necessitates permitting the escape of gases after the ingot is cast in the mold, making it necessary to prolong the cooling period so as to preserve the fluid condition for the release of the gases. The addition of fluorspar or other fluorides in amounts of 1 to 6 ounces per 3000 pounds

of steel is effective for producing this result. The fluorspar is preferably added in the mold after about six inches of the metal has been poured therein and its use provides an ingot which is freer from blowholes and freer from puffiness at the top and of much better appearance than the untreated rimmed ingots.

1,672,172, Method of Annealing Sheet Metal, Wilhelm Reuss, of Altena, Germany, Assignor to Joh. Moritz Rump A.-G., of Altena, Germany, a joint stock company of Germany.

This patent describes a method of annealing metal sheets for the production of diaphragms in telephony and radio industry which are free from tension. The process comprises assembling the sheets or strips (b) within an annealing box (a) so as to fit the whole of the box and placing between piles of the sheets plates (c) of a material having a co-efficient of
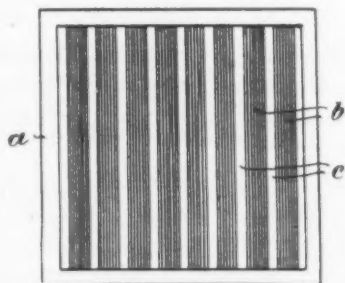
expansion higher than that of the strips to be annealed. The box is then heated to a temperature of 750 to 1100 degrees Fahr. (400 to 600 degrees Cent.) in an annealing furnace and thereafter slowly cooled. Upon removal of the strips from the box, they are found to be perfectly plain and free from tension. The greater expansion of the metal strips (b) during the heating operation causes a small interstice between the strips removed and the strips forced against the walls of the box so that all irregularities are removed therefrom.

1,672,180, Treatment of Metal Surfaces, Walter Smith, of West Hartlepool, England, Assignor to The Expanded Metal Company, Limited, of London, England.

This patent describes a process of treating metal surfaces to prevent corrosion thereof which comprises subjecting the oxidized surface of the metal to the action of carbon disulphide vapor which produces a coating of sulphide of the base metal which effectively resists further corrosion.

1,672,444, Producing Corrosion-Resistant Surfaces on Metals, Frederick M. Becket, of New York, N. Y., Assignor to Electro-Metallurgical Company, a corporation of West Virginia.

This patent describes a method of producing a corrosion resisting surface on metals by a cementation process, and the improvement consists in mixing silicon with powdered chromium used in chromizing to prevent the superficial oxidization of the chromium, so as to permit the cementation or chromizing process to be carried on with ordinary combustion gas or other fuels.

1,660,790, Process of Preparing Alloy Steel for Die Blocks and Other Purposes, Gilmore N. Herman, of Chicago, Assignor to Alloy Steel Corp., of Chicago, a Corporation of Illinois.

This patent describes an alloy steel particularly for die blocks which has the strength, durability and toughness desired, but will not be too hard to be machined, or to be trimmed down for resinking after it has been used to the extent that resinking is necessary. The alloy used for this purpose preferably comprises chromium 0.75 to 0.95 per cent, molybdenum 0.30 to 0.50 per cent and nickel 2.75 to 3.25 per cent with carbon 0.40 to 0.50 per cent. It is cast into an ingot, allowed to solidify, then heated to a temperature of 1800 to 2300 degrees Fahr. and without allowing it to cool below a surface temperature of approximately 1000 degrees Fahr. is forged into die blocks and the forging then annealed to a temperature of 1400 to 1700 degrees Fahr. and allowed to cool slowly and uniformly. The finished die block requires no hardening or subsequent tempering.

1,661,907, Steel Alloy and Process of Making the Same, Edmund Pakulla, of Remscheid, Germany, Assignor, by Mesne Assignments, to Deutsche Edelstahlwerke Aktiengesellschaft, of Bochum, Germany, a Corporation of Germany.

This invention relates to the manufacture of permanent magnets from ordinary high speel steel which is heated to a temperature a little higher than the "lowering temparture", (i. e., the temperature at which certain sorts of steel must be heated in order to lower the Ar_1 transformation when cooling the steel,) and then quenching the same in a mild, non-aqueous hardening agent.

1,667,966, Alloy, Michael G. Corson, of Jackson Heights, New York, Assignor to Electro Metallurgical Company, a corporation of West Virginia.

This patent describes a quaternary copper alloy with the general properties of binary and ternary aluminum bronzes, but being more resistant to corrosion. The alloy is produced by adding chromium and nickel to molten aluminum bronze of the alpha type to produce an alloy containing not over 9 per cent aluminum and more than 0.5 per cent chromium. The nickel is used to hold the chromium in solution.

1,669,109, Induction Furnace, James M. Weed, Schenectady, N. Y., assignor to General Electric Company.

This patent covers an induction furnace comprising a primary winding, a refractory receptacle providing a looped cavity adapted to contain a liquid charge constituting a secondary. The primary and secondary are structurally so related that the spacing from the primary of sections of the secondary in planes passing through the axis of the primary increase progressively from one end of the sections to the other, through a passage external to the secondary. The charge circulates between a portion of the secondary spaced different distances from the primary.

1,669,563, Heating Kiln, Boyd M. Johnson, Metuchen, N. J., assignor to The Carborundum Company, Niagara Falls, N. Y.

A baffle is arranged between the combustion chamber and the heating compartment of this furnace. This baffle has its lower portion of higher thermal conductivity than its upper portion.

THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each week with a specially prepared section of The Engineering Index Service. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the Weekly Card Index Service of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,700 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

AIRCRAFT MANUFACTURE

METALLURGY. Metallurgy in Aircraft, H. C. Knerr. *Can. Machy. (Toronto)*, vol. 39, no. 10, May 17, 1928. pp. 42 and 67-68.

Metallurgical problems to be solved in production of aircraft; substitution of metal for wood claims to have resulted in reduction in weight, improvement in strength and reliability, minimum risk in crash or fire, and, on production basis, lower manufacturing costs; new materials adopted; prevention of corrosion; aluminum enamel. Summary of paper presented before Am. Soc. Steel Treating.

STEEL TUBING. Inspection of Aircraft Tubing, H. C. Knerr. *Areo Digest*, vol. 12, no. 5, May, 1928, pp. 818 and 820.

Cold-drawn, slightly tempered after drawing, normalized or oil-quenched and tempered chromium-molybdenum steel popular; specifications for standard aircraft tubing used by Army, Navy and commercial builders; testing each individual tube in lot of alloy steel; after normalizing chromium-molybdenum steel tubes show Rockwell hardness of 90B and mild carbon below 80B; results of tests. Reprinted from "Iron Age."

AIRCRAFT PARTS

SHERARDIZING. Sherardizing for Rust Proofing Aeroplane Parts, H. N. Lead. *Can. Machy. (Toronto)*, vol. 39, no. 11, May 31, 1928, pp. 42-43, 3 figs.

Aircraft parts to be sherardized are placed in drum with first layer of zinc dust, then layer of material or parts, then another layer of zinc dust; furnace loaded and drum rotated in it; drums are allowed to cool and must not be opened at above 200 degrees Fahr.; method of testing deposit; preparing zinc dust.

AIRPLANE PROPELLERS

ALUMINUM ALLOY—ETCH TEST. Etching of Aluminum Alloy Propellers, A. Lyon. *Aviation*, vol. 24, no. 21, May 21, 1928, pp. 1456-1457 and 1475-1478, 7 figs.

Light etch used in manufacturing and when in use, for detecting defects in propellers that may cause failure; surface subjected to caustic-soda solution for short period, rinsed in water and deposit of copper forming during etching operation removed with water solution of nitric acid; final washing and drying; propeller deep-etched locally for identifying defects.

AIRPLANES

WELDING. Vital Parts of Ford Plane Welded. *Welding Engr.*, vol. 13, no. 5, May, 1928, pp. 41-43, 7 figs.

Steel and aluminum members of all-metal planes are welded; duralumin still presents welding problem; numerous points in big planes where unusual strains are involved, requiring high-strength steel tubing and welded joints.

ALLOYS

AGE HARDENING. Age-Hardening of Alloys, Hay. *Iron and Steel of Canada (Gardenvale, Que.)*, vol. 11, no. 5, May, 1928, pp. 148-150.

General mechanism of age hardening depended upon size of particles present in alloy; depression after quenching and before hardening commenced; temperature of precipitation caused difference in amount of hardening; time of soaking at high temperature before quenching; size of article influences degree of hardness by age-hardening attainable; volume change due to precipitation of compound from solution caused by

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age-hardening. Paper read at Inst. of Metals.

SULPHUR DETERMINATION. Report of Committee B-4 on Metallic Materials for Electrical Heating. *Am. Soc. Testing Matls. —Reprint,* no. 20, for mtg. June 25, 1928, 8 pp., 1 fig.

Proposed tentative methods of determination of sulphur in metallic materials for electric heating.

ALLOY STEELS

AUTOMOTIVE—NORMALIZING. Many Production Advantages Offered by Normalized Steel, C. N. Dawe. *Automotive Industries,* vol, 58, no. 23, June 9, 1928, pp. 876-878, 16 figs.

Change from heat treating to normalizing operations for certain vital automotive parts introduced by Vanadium Corp. of America; absence of strains makes it unnecessary to resort to cold straightening; carbon-vanadium steel is ideal; properties consumer must demand when using normalized steel on production basis; molybdenum steels; vanadium does not air-harden.

MANUFACTURE. Electric Furnace Widely Employed for Making Alloy Steel, W. H. Priestly. *Iron Trade Rev.,* vol. 82, no. 23, June 7, 1928, pp. 1472-1474, 2 figs.

Discussion of paper on "The Manufacture of Alloy Steels" by E. C. Smith, presented before Am. Iron and Steel Inst.; good practice to melt with heavier slags, rich in lime and low in iron oxide; much cracking and tearing of ingots in rolling, might be eliminated if steel were poured through small nozzles at as low temperature as consistent with good practice; changes taking place in methods of melting alloy-steel tonnage.

MANUFACTURE. The Manufacture of Alloy Steel, E. C. Smith. *Iron Age,* vol. 121, no. 22, May 31, 1928, pp. 1532 and 1578-1579.

Trends of alloy steel manufacture; control of charge necessary; furnaces and fuels used; many intangibles included in customer's demands; methods of adding alloys; ingot practice must be good; slow rolling in smooth rolls. Abstract of paper presented at Am. Iron and Steel Inst.

MANUFACTURE. Alloy Steels — Their Manufacture, Properties, and Uses, H.C.H. Carpenter. *Chem. News (Lond.),* vol. 136, no. 3553, May 18, 1928, pp. 307-310.

Deals with tungsten, chromium and manganese steels, influence of tungsten on melting points and inversions of steels; properties and uses; manufacture of chromium steels. (To be continued.) Second Cantor Lecture delivered before Roy. Soc. of Arts.

ALUMINUM, ACID RESISTING

Action of Hydrochloric Acid on Extra-Pure Aluminum (Action de l'acide chlorhydrique sur l'aluminium extra-pur), J Calvet. *Académie des Sciences—Comptes Rendus (Paris),* vol. 186, no. 6, Feb. 6, 1928, pp. 369-371.

Resistance to action of 2.5N-hydrochloric acid at 18 deg. previously recorded for extra-pure aluminum is only temporary and after few days metal is attacked at rate which increases with time and finally remains constant.

ALUMINUM BRONZE

INGOT SEGREGATION. Reversed Ingot Segregation in Aluminum Bronze (Zur Kenntnis der umgekehrten Blockseigerung bei Aluminiumbronze), W. Claus and F. Goederitz. *Giesserei (Duesseldorf),* vol. 15, no. 17, Apr. 27, 1928, p. 398, 1 fig.

Preliminary report of results of test on aluminum bronze with content of 4.5 per cent aluminum and 95.5 per cent copper.

ALUMINUM, NICKEL PLATING

The Electrodeposition of Nickel on Aluminum, C. H. Proctor. *Brass World,* vol. 24, no. 5, May 1928, pp. 153-154.

Report of research work, done by H. K. Work, at Mellon Institute, Pittsburgh, under fellowship established by Aluminum Co. of America; final results of research work of Work.

ALUMINUM ALLOYS (ALMELEC)

Almelec A New Light Alloy for Wires and Cable Conductors. *Mech. World (Lond.),* vol. 83, no. 2158, May 11, 1928, pp. 347.

Details of physical constants of aluminum alloy developed in France for aerial power-transmission and telephone lines; contains 98.5 per cent pure aluminum and 1.2 per cent of magnesium and silicon and is subjected to special heat treatment in addition to being hard drawn; resistance to corrosion under atmospheric conditions is stated to be comparable with that of pure aluminum. Brief abstract translated from Revue Générale d'Electricité.

ALUMINUM ALLOY CASTINGS

Effect of Melting and Pouring Conditions upon the Quality of No. 12 Aluminum Alloy Sand Castings, T. W. Bossert. *Metal Industry (Lond.),* vol. 32, no. 21 and 22, May 25 and June 1, 1928, pp. 520-521 and 542.

Paper read before Am. Foundrymen's Assn., previously annotated.

ALUMINUM ALLOYS

HEAT TREATMENT. Heat Treatment of Aluminum and Its Light Alloys, R. J. Anderson. *Fuels and Furnaces,* vol. 6, no. 5, May 1928, pp. 617-618, 2 figs.

Quenching heat treatment of aluminum alloys; consists in heating to some elevated temperature and then rapidly quenching in some suitable medium; these alloys are hot short and readily distorted at high temperatures. (Continuation of serial.)

HEAT TREATMENT. Heat Treatment of Aluminum and Its Light Alloys, R. J. Anderson. *Fuels and Furnaces,* vol. 6, no. 6, June 1928, pp. 763-764, 2 figs.

Aging treatment of aluminum alloys after quenching. (Continuation of serial.)

MANUFACTURE. The Production of Workable Aluminum Alloys (Wissenschaftliche und technische Hilfsmitted und Erfordernisse bei der Herstellung verguetbarer Al-Legierungen), P. Schwerber. *Giesserei (Duesseldorf),* vol. 15, no. 18, May 4, 1928, pp. 420-424.

Describes methods of producing so-called high-grade aluminum alloys which, through thermal treatment, acquire four times breaking strength of pure annealed aluminum; such alloy has strength properties of good ingot steel with only about one-third its weight.

SELF HARDENING. Self Hardening Light Alloys, E. V. Pannell. *Am. Metal Market,*

vol. 35, no. 34, Feb. 21, 1928, p. 4.

Certain distinct fields of use, for forgings and certain classes of sheet, and for light-alloy piston castings; two recent groups of alloys have been recently introduced in Germany under proprietary names, Alneon and Neonalium, which show marked improvement after stated period; developed by M. O. Wurmback; they are cheap, easily cast and require no difficult after treatment.

AUTOMOBILES

BODIES, STEEL. Sheet Steel for Automobile Bodies. *Heat Treating and Forging*, vol. 14, no. 5, May 1928, pp. 492-497, 12 figs.

Sheet mills and hot rolling practice in making black sheet from sheet bar; defects arising in hot rolling; influence of hot and cold work on structure and properties of sheet steel; mechanical features of hot mills; method of warming-up rolls; pair and sheet furnaces; breakdown of bars; hot-mill finishing; direction properties of black sheet. (Continuation of serial.)

BODIES, STEEL. Sheet Steel for Automobile Bodies. *Blast Furnace and Steel Plant*, vol. 16, nos. 4 and 5, Apr. and May 1928, pp. 489-491, 617-622 and 640, 12 figs.

April: Rolling of sheet bar and passes used; defects which affect finished sheet; relation of gage and bar weights and chemical variations; design of sheet-bar rolls; six or seven reductions to definite size before resulting sheet bar is run out onto cooling table as finished. May: Metallurgical study of low-carbon grade of steel used for sheets; critical points and transformations; banded structure; grain growth. (Continuation of serial.)

AUTOMOBILE ENGINES

PISTONS, ALUMINUM ALLOY. Light Alloys for Pistons of Automotive Engines (Leichtmetall-Legierungen fuer Kraftwagenkolben), H. Reininger. *Maschinenbau (Berlin)*, vol. 7, no. 8, Apr. 19, 1928, pp. 370-373, 6 figs.

Advantages for using aluminum and other light alloys in construction engine pistons; what is required of such alloys; variation of tensile strength of German and American aluminum castings with temperature; analyses, tests and microstructure of German aluminum alloys used for casting of pistons.

AUTOMOBILE PARTS

HEAT TREATMENT. Chrysler Parts Heat Treated Semi-Automatically, F. W. Curtis. *Am. Mach.*, vol. 68, no. 21, May 24, 1928, pp. 836-838, 6 figs.

Automatic time and temperature control reduces amount of rejected work, increases production and lowers heat-treating costs of miscellaneous automotive parts; heat treating furnaces at Chrysler Corp. Detroit plant: some furnaces operate automatically, cycle including transportation of work through heating chamber, time limit of heating, control of temperature and quenching; others require hand operation for quenching.

HEAT TREATMENT. Automobile Parts Heat Treated in Pusher Type Furnaces. *Fuels and Furnaces*, vol 6, no. 5, May 1928, pp. 685-687, 4 figs.

Automobile parts, consisting of crankshafts, axle shafts and other miscellaneous parts are heat treated in battery of nine gas-fired fur-

naces arranged in tandem units for various heat treating operations; all of forging and heat treating furnaces in this plant are equipped with automatic temperature-control instruments.

BEARINGS

BRONZE. Bronze Bearings for Heavy Duty, N. K. B. Patch. *Iron Age*, vol. 121, no. 23, June 7, 1928, pp. 1599-1600.

New conditions met by proper design and crystal structure for bearings; selecting right material; bearing is mixture of hard and soft crystals; harder bronzes are not only improvement but are essential to long life; laboratory control necessary; too many oil grooves a common error; every oil groove in bearing reduces bearing area; oil groove should be well chamfered at its edges, so as not to scrape film from journal; vital factors in design of bearings.

BRIDGES, SUSPENSION

CABLE STEEL. Manufacture of Acid Open-Hearth Steel For Suspension Cables, H. C. Boynton. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 6, June 1928, pp. 949-952.

Author explains why his firm (J. E. Roeblings Sons Co., Trenton, N. J.) considers acid open-hearth steel superior to basic; acid open-hearth steel is free from solid nonmetallic impurities; it has greater freedom from included gases; with same chemical composition it practically always has higher tensile strength and elastic limit than basic open-hearth steel; it has greater uniformity day in and day out in physical, chemical and microscopical properties.

CADMIUM PLATING

Cadmium and Zinc, C. H. Proctor. *Brass World*, vol. 24, no. 5, May 1928, pp. 155-156.

Steady growth in commercial value of these protective coatings to metal-fabricating industries; cadmium is one of easiest metals to deposit upon steel, cast or malleable iron. Abstract of paper read before Am. Electroplaters' Soc.

CASE HARDENING

A New Free-Cutting Case Hardening Steel. *Machy. (Lond.)*, vol. 32, no. 814, May 17, 1928, pp. 213-214.

Samples of new mild steel under name of Jalcase have been tested at City of Birmingham Industrial Research Laboratories and results of these tests, together with comments made thereon are reproduced.

CARBURIZING COMPOUNDS. Production Tests of Carburizing Compounds, J. S. Ayling. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 6, June 1928, pp. 1039-1042.

Describes short, concise and inexpensive method of testing relative merits of various carburizing compounds under actual production conditions as used in any heat treatment department; method gives comprehensive and practical figure as to merit of any carburizing compound in respect to any other compound as used in actual practice under individual shop conditions.

CYANIDE PROCESS. Case Hardening and the Heat Treatment of Steel by Sodium Cyanide. *Machy. Market (Lond.)*, no. 1438, May 26, 1928, pp. 477-478, 3 figs.

Case hardening processes involving use of

cyanide salts in liquid form; type of furnace efficient and economical; to procure uniform results it is necessary to keep percentage content of cyanide constant; best method to ensure constancy is to regenerate with pure sodium cyanide.

MACHINE PARTS. Case Hardening of Machine Parts, A. J. Smith. *Commonwealth Engr. (Melbourne)*, vol. 15, no. 8, Mar. 1, 1928, pp. 317-318, 3 figs.

Economies effected by continuous working; process briefly described; figures showing results obtained in Packard works; summary of temperature distribution through 24-foot furnace of type described.

NITRATION. On the Application of Nitration to Certain Special Steels (Sur les applications de la nitruration de certains aciers speciaux), L. Guillet. *Académie des Sciences—Comptes Rendus (Paris)*, vol. 186, no. 18, Apr. 30, 1928, pp. 1177-1180.

Treats of use in hardening explosion engine cylinders and crankshafts and effect on life of each.

NITRATION. Application of Nitration to Certain Special Steels (Les applications de la nitruration de certain aciers spéciaux), L. Guillet. *Génie Civil (Paris)*, vol. 92, no. 2386, May 5, 1928, p. 446.

Explosion engine cylinders and crankshafts treated by nitration.

CAST IRON

GROWTH. Growth of Cast Irons, E. Morgan. *Brit. Cast Iron Research Assn.—Bul. (Birmingham)*, no. 20, Apr. 1928, pp. 7-17.

Definition of growth; why cast irons grow; influence on growth of manner in which heat is applied; effect of time and temperatures; effect of oxidizing medium; effects of elements usually present in cast irons; influence of dissolved gases; possibility of preventing growth in gray cast irons.

HIGH TEST—MANUFACTURE. Developments in Furnace Practice for Production of High-Test Cast Iron, R. Moldenke. *Fuels and Furnaces*, vol. 6, no. 5, May 1928, pp. 726-730.

Control of form of graphite in cast iron by use of proper charge, correct furnace and pouring temperatures, and use of special molds, results in improved physical properties of high-test cast iron; use of steel scrap; alloy cast iron; pearlitic cast iron; influence of graphite formation; influence of superheating upon formation of graphite; low-silicon and low-carbon cast iron.

MACHINABILITY. Machinability and Wear of Cast Iron. *Soc. Automotive Engrs.—Jl.*, vol. 22, no. 6, June 1928, pp. 641-643.

Discussion of T. H. Wickenden's annual meeting paper with brief abstract of paper; lubrication is prime essential; lubrication maintained; lessons from veteran cars; tests for machinability; hardness and machinability not related.

PROPERTIES. Mechanical and Physical Properties of High-Grade Cast Iron and Principles Underlying Its Production (Hochwertiger Grauguss, seine mechanisch-physikalischen Eigenschaften und die Grundlagen seiner Erzeugung), E. Zimmermann. *Zeit. fuer die gesamte Giessereipraxis (Berlin)*, vol. 49, nos. 18, 19 and 20, Apr. 29, May 6 and 13, 1928, pp. 159-160, 166-167 and 175-176, 9 figs.

Apr. 29: Tensile and hardness in relation

to pearlite content; calculation of constituents from analysis of cast iron. May 6: Volume determination. May 13: Metallography. (Concluded.)

PROPERTIES. The Metallurgical Aspects of Cast Iron, P. W. Blackwood. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 6, June 1928, pp. 1023-1038.

Cast iron has not generally been regarded with great favor because of its low physical properties and heterogeneity and low price has had tendency to handicap development of cast irons of higher quality; it is generally regarded as simple alloy of iron and carbon; it is really not so simple, but rather complex material consisting of free bodies, compounds and mixtures of compounds; factors which influence properties are discussed; work of various investigators on effect of additions of various elements to cast iron.

COPPER-TIN ALLOYS

On the Equilibrium Diagram of the Copper-rich Side of the Copper-Tin System, T. Matsuda. *Tohoku Imperial University—Science Reports (Sendai, Japan)*, vol. 17, no. 2, Mar. 1928, pp. 141-161, 22 figs. partly on supp. plates.

Equilibrium diagram was studied by means of thermal analysis and electric-resistance measurement.

CHAINS WROUGHT IRON

FAILURE. Chain and Cable Failures, H. J. Gough and A. J. Murphy. *Mech. World (Manchester)*, vol. 83, no. 2159, May 18, 1928, p. 363.

Causes of chain failure should be investigated in systematic manner; very lengthy research program has now been completed; gives results of research; progressive deterioration of welded joints is clearly demonstrated; conclusions drawn from results of research. Abstract of paper read before Instn. Mech. Engrs.

CHROMIUM ALLOYS

WELDING. Welding of High-Chromium Alloys. *Welding Engr.*, vol. 13, no. 5, May 1928, pp. 43-45.

For purpose of this study all commercial chromium alloys are divided into six groups in accordance with different prescribed methods of welding; rustless iron; stainless steel; rustless or stainless iron; extra high chromium alloys; castings.

CHROMIUM PLATING

Chromium Plating for Wearing Parts and Cutting Edges. *Am. Mach.*, vol. 68, no. 22, May 31, 1928, p. 892.

Hardness of chromium itself opened new fields of usefulness; worn gages built up to size by deposit of chromium and new gages were made to allow for plating of chromium; use on cutting tools; drills and spindles for machine tools chromium plated.

CHROMIUM STEEL

HEAT RESISTING. Heat Resisting Steels —Mechanical Properties, W. H. Hatfield. *Iron and Coal Trades Rev. (Lond.)*, vol. 116, no. 3142, May 18, 1928, pp. 739-742.

Mechanical strength of steels at high temperature, as affected by introduction of special elements; conditions of test; tensile tests at every 100 degrees Cent. up to 1000

degrees Cent. on carbon steels; hardened and tempered high-tensile alloy steels; chromium, silicon-chromium and chromium-nickel-tungsten steels; analyses and condition of steels. Abstract of paper read before Iron and Steel Inst.

HEAT RESISTING. Heat Resisting Steels —Mechanical Properties, W. H. Hatfield. *Iron and Steel Inst.—advance paper (Lond.),* no. 6, May 1928, 22 pp.

Deals with mechanical strength of steels at high temperature, as affected by introduction of special elements; steels investigated include chromium, silicon-chromium, chromium-nickel, chromium-nickel-silicon and chromium nickel-tungsten series. See abstract in Engineering (Lond.), vol. 125, nos. 3252 and 3253, May 11 and 18, 1928, pp. 589 and 622 and discussion on pp. 601-602.

STRUCTURE. Structure of High-Percentage Chromium Steel (Das Gefuege von hochlegiertem Chromstahl), P. Schoenmaker. *Stahl u. Eisen (Duesseldorf),* vol. 48, no. 18, May 3, 1928, pp. 591-593, 11 figs.

Discusses influence of chromium on alloy steel; results of tests show that addition of nickel to high-percentage chromium steel contributes to formation of austenite but is not absolutely necessary; high chromium content and high hardening temperature are all that are required.

CRYSTALS

CHEMICAL PROPERTIES. The Chemical Properties of Crystals, C. H. Desch. *Engineer (Lond.),* vol. 145, no. 3774, May 11, 1928, pp. 513-514.

Chemical properties of crystals are, like their cohesion and their electric conductivity, intimately bound up with character of their space lattice, since it is outer or valency electrons which are concerned in chemical reactions, behavior of atom in solid states is likely to be profoundly modified by its geometrical relations to its neighbors, on account of deformation of electron orbits. 18th May Lecture to Inst. of Metals.

ETCHING. The Nature, Origin and Interpretation of the Etch Figures on Crystals. *Nature (Lond.),* vol. 121, no. 3052, Apr. 28, 1928, pp. 666-668.

Review of book by A. P. Honess published by J. Wiley and Sons; presents historical discussion under following main heads: methods, process of growth of etch figure and its interpretation, anomalous etchings, etch figure and isomorphism; in special section are brought together results of author's own investigations on some ten mineral species, representing six classes of symmetry.

DURALUMIN

INTERCRYSTALLINE CORROSION. Corrosion Embrittlement of Duralumin—The Use of Protective Coatings, H. S. Rawdon. *Nat. Advisory Committee for Aeronautics—Tech. notes,* no. 285, Apr. 1928, 31 pp., 9 figs.

Although corrosion resistance of sheet duralumin is improved by suitable heat treatment, protection of surface is still necessary for long life; varnish and oxide types, and metallic coatings, of which aluminum appears most promising; test methods; character of surface has noticeable effect upon rate of corrosive attack; oxide coatings produced by anodic method; aluminum coatings applied by metal spraying.

ELECTRIC FURNACES

Electrochemists Discuss Problems Related to Electric Heating. *Foundry,* vol. 56, no. 10, May 15, 1928, pp. 390-391.

Review of meeting of American Electrochemical Society; roundtable discussion on refractories; refractories trail furnace design; electricity widely used; annealing of nonferrous metals in electric furnace.

HEAT TREATING. Mechanization of Electric Annealing and Hardening Furnaces (Mechanisierung elektrischer Glueh- und Haerteoefen), H. Nathusius. *Stahl u. Eisen (Duesseldorf),* vol. 48, no. 21, May 24, 1928, pp. 694-696, 6 figs.

Describes automatic loading and unloading arrangement used in America on Hagan resistance furnaces.

HIGH FREQUENCY. New High Speed Steel Made in Induction Furnace. *Iron Age,* vol. 121, no. 23, June 7, 1928, p. 1619, 1 fig.

Description of Ajax-Northrup high-frequency electric induction furnace with capacity of 450 lb. per heat, installed at Imperial Steel Works of Edgar Allen and Co., Inc., Sheffield; one hour completes 450-lb. heat; advantages over crucible process; high-speed steel of extra durability made.

HIGH FREQUENCY. Evolution of Induction Furnaces of High Frequency (L'evolution du four à induction à haute fréquence), R. Sevin. *Jl. du Four Electrique (Paris),* vol. 37, no. 5, May 1928, pp. 137-140, 4 figs.

Generation of high frequency by spark gap; laboratory and industrial furnaces; use of special alternators.

HIGH FREQUENCY. High Frequency Heating. *Elec. Rev. (Lond.),* vol. 102, no. 2636, June 1, 1928, pp. 943-945, 3 figs.

Comparative review of methods of generating currents necessary for supplying high-frequency furnaces; salient advantages of high-frequency heating; Tesla type of generator; tube-type generator; shows diagrammatically lay-out for high frequency furnace installation with thermionic-tube generator.

REGULATION. Regulation of Arc Furnaces of Constant Intensity (Le réglage des fours à arcs à intensité constante), M. Mathieu. *Arts et Metiers (Paris),* vol. 81, no. 92, May 1928, pp. 185-187, 2 figs.

Mechanism of control; limiting conditions and conditions of speed of action of regulator on furnace arcs.

IRON MELTING. Electric Smelting High Grade Black Sand. *West. Machy. World,* vol. 19, no. 5, May 1928, pp. 213-215, 2 figs.

Use of electricity for direct smelting of black sands, with no gangue to be fluxed and smelted, is most feasible method of smelting; photomicrographs with description of each made from samples of iron in writer's possession made from black-sand ores of magnetite, minus any foreign additions.

VACUUM, HIGH FREQUENCY. A Simple High-Frequency Vacuum Furnace for Laboratory Purpose (Ein einfacher Hochfrequenz-Vakuumofen fuer Laboratoriumszwecke), E. W. Fell. *Archiv fuer das Eisenhuettenwesen (Duesseldorf),* vol. 1, no. 10, Apr. 1928, pp. 659-661, 2 figs.

Description of vacuum furnace with high-frequency heating for production of pure metal charges.

ELECTRIC HEATING

INDUSTRIAL. Industrial Electric Heating, O. Wilhelmy. *Elec. Light and Power*, vol. 6, no. 6, June 1928, pp. 65-66 and 116-117, 5 figs.

Details as to variety of applications; applications of electric heat in stereotype melting; mat drying and scorching by electric heat.

INDUSTRIAL. Report of Committee on Electric Heat, G. H. Schaeffer. *Iron and Steel Engr.*, vol 5, no. 6, June 1928, pp. 291-303, 11 figs.

Welding; trend of power cost; industrial heating; electric annealing furnaces; 1200 to 1850 degrees Fahr. vitreous enameling; hardening and drawing; miscellaneous box-type and vertical-cylindrical furnaces; japanning; electric-furnace losses; methods of electric welding; electric-welding equipment; materials suited to welding; types of electrically welded joints; automatic welding head; applications.

FORGE SHOP PRACTICE

Pressing Metal Alloys. *Automotive Abstracts*, vol. 6, no. 5, May 20, 1928, p. 151.

Deals with warm pressing of duralumin copper and brass; temperature and type of furnaces to use and precautions which are necessary to attain desired results. Brief abstract translated from Werkzeugmaschine. Mar. 15, 1928, pp. 101-105.

FORGING MACHINES

Forging and Plate-Working Machines (Les machines de forge et de chaudronnerie), L. Gendron. *Pratique des Industries Mécaniques (Paris)*, vol. 11, no. 2, May 1928, pp. 63-69, 14 figs.

Describes forging presses, hammers and rolls, also plate-forming presses and stamping presses. (To be continued.)

FORGINGS, STEEL

HEAT TREATMENT. Mass Effect in the Heat Treatment of Large Forgings, J. A. Jones. *Metallurgist (Supp. to Engineer, Lond.)*, May 25, 1928, pp. 70-72.

Influence of mass in heat treatment of alloy steels can be illustrated by tests taken from properly treated forgings of different compositions; gives tables of mechanical properties at middle of wall and at outside, and mechanical properties of large forgings and of small pieces which have received same treatment. (To be continued.) Communication from Research Department, Woolwich.

FURNACES

ANNEALING. Circular Annealing Furnace is Success, J. Strauss. *Iron Trade Rev.*, vol. 82, no. 22, May 31, 1928, pp. 1406-1408, 5 figs.

Furnace designed originally for special castings at naval gun factory; results demonstrate superior features; simplicity, convenience and economy claimed for new type; one-piece roof, 26 feet in diameter overall and weighing about 25 tons; close temperature control.

ANNEALING, NORMALIZING. Continuous Normalizing Furnace Reduces Annealing Time, F. W. Manker. *Iron Trade Rev.*, vol. 82, no. 20, May 17, 1928, pp. 1276-1277, 3 figs.

Requirements for satisfactory normalizing furnace; normalizing furnaces used at plant of Empire Steel Corp. and equipment included; furnaces divided into three zones, preheating, heating and cooling; temperatures in these zones maintained by three automatic pyrometric controls; normalizing eliminates at least one box anneal and for some grades of sheets, box annealing is eliminated entirely.

ANNEALING, STOKERS. Stokers Applied to Annealing Furnaces, J. B. Whitlock. *Heat Treating and Forging*, vol. 14, no. 5, May 1928, pp. 539-541, 5 figs.

Annealing-furnace stokers with boiler type effect improvements in annealing practice; fuel saving considerable; temperature control easily maintained; furnace construction; fuel economy.

HEAT TREATING, CONTINUOUS. Mass Production Heat Treatment, J. W. Urquhart. *Machy. (Lond.)*, vol. 32, no. 812, May 3, 1928, p. 155.

Continuous-action automatic furnace; pusher type of furnace is undoubtedly parent of present ambitious attempts; system has now been so far developed that it is for smaller mass-produced class of goods, entirely automatic; heat distribution and temperature control.

HARDNESS TESTING

Study and Industrial Control of Annealing and Cold Working by Ball Testing under Light Loads (Etude et controle industriel du recuit et de l'écrouissage par l'essai à la bille sous faible charge), N. Nicolau. *Revue de Métallurgie (Paris)*, vol. 25, no. 3, Mar. 1928, pp. 155-168, 7 figs.

Comparison of method used for copper and brass annealing control, particularly for cartridge cases; author has developed simple and precise method of control by hardness test with balls of small diameter under light load; arrangement for testing and machine used; how to analyze test results; advantages of method.

HARDNESS TESTING MACHINES

ROCKWELL—CALIBRATION. Calibration of Rockwell Hardness Testing Machines, F. S. Mapes. *Am. Soc. Testing Matls.—Preprint*, no. 97, for mtg. June 25, 1928, 4 pp., 1 fig.

Scheme involved steel bar supported on knife edges with load applied at center; with dial gage below load, deflections of bar could be accurately measured; by using this device in standard vertical testing machine with loads of 10,100, and 150 kg. applied, bar was calibrated; set-up transferred to Rockwell hardness-testing machine and check deflections secured; method being simple, accurate and inexpensive, it is readily adaptable to commercial use.

HARDNESS TESTS

BRINELL. The Recovery and Sinking-In or Piling-Up of Material in the Brinell Test, and the Effects of these Factors on the Correlation of the Brinell With Certain Other Hardness Tests, A. L. Norbury. *Iron and Steel Inst.—Advance Paper (Lond.)*, no. 10, May 1928, 15 pp.

Sinking-in or piling-up of material surrounding Brinell impressions have constant value for given material, irrespective of size of impression, if expressed as percentage of measured depth of impression.

HIGH SPEED STEEL

Effects of Antimony, Arsenic, Copper and

Tin in High Speed Tool Steel, H. J. French and T. G. Digges. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 6, June 1928, pp. 919-940, 13 figs.

Relates to effects of added (not residual) antimony, arsenic, copper and tin on low-tungsten high-vanadium high-speed tool steel; hot working and machining properties, hardness after different heat treatments, metallographic features and tool performance in both rough turning and finish turnings are considered.

STRUCTURE. Influence of the Structure As Cast Upon Manufacturing and Qualities of Some Alloyed Especially High Speed Steels, F. Rapatz. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 6, June 1928, pp. 1009-1022, 12 figs.

Great many steels, especially high speed and high alloy chromium steels used contain constituent corresponding to eutectic of pig iron and these steels metallographically are pig iron; influence of various freezing conditions in practical manufacturing; examples of influence of forging; melting point of eutectic corresponding to ledeburite is only slightly altered with chromium up to 14 per cent whereas in high speed steels this point rises to 2370 degrees Fahr.

IMPACT TESTING

NOTCHED-BAR. Standard Notched-Bar Testing (Welche kleine Kerbschlag-Normalprobe), P. Fischer. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 17, Apr. 26, 1928, pp. 541-547, 32 figs.

Discussion of best-known forms of notched-bar tests; recommendations for standard tests; it is recommended in future to use Mesnager tests as smaller standard test in connection with large Charpy test.

IRON ALLOYS

ELECTRIC FURNACE MANUFACTURE. Manufacture of Iron-Carbon-Titanium Alloys in Electric Furnaces (La fabrication du ferro-carbo-titane au four electrique), S. Heuland. *Jl. du Four Electrique (Paris)*, vol. 37, no. 5, May 1928, pp. 142-144.

Principles of manufacture, calculation of mixture, of addition of lime, carbon and iron to ilmenite and furnace utilized; process of manufacture.

GRAPHITE SOLUBILITY. The Solubility of Graphite in Molten Iron-Carbon Alloys (Die Aufloesungsgeschwindigkeit von Graphit in geschmolzenen Eisen-Kohlenstoff-Legierungen), F. Sauerwald and A. Koreny. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 17, Apr. 26, 1928, pp. 537-540, 2 figs.

Results of laboratory tests to determine velocity of dissolution at 1255 and 1350 deg. cent.; quantitative determination of isotherms obtained according to law of Noyes, Withney and Nernst, taking into consideration change in surface; comparison with experiences of Bardenheuer and Hanemann; temperature has considerable influence on solubility.

IRON, ANNEALED

TWIN CRYSTALS. Twin-Like Crystals in Annealed Iron, H. O'Neill. *Iron and Steel Inst.—Advance Paper (Lond.)*, no. 11, May 1928, 92 pp., 8 figs.

Small ferrite grains found embedded within large crystals of piece of decarburized steel plate were examined metallographically; they had been prepared by method of strain-

ing and annealing; study of form of boundaries, pressure figures and etch pits indicates that small grains are twins; results are consistent with fluorite type of twinning; bibliography.

IRON CASTINGS

DEFECTS. Hidden Defects in Iron Castings, P. R. Ramp. *Iron and Steel (Gardenvale, Que.)*, vol. 11, no. 5, May 1928, pp. 140-143, 4 figs.

Method of localizing shrink cavities and blowholes to places where they cannot harm casting; if casting is so molded that all defects will appear on surface, or will be discovered during machining, there will be fewer failures in service; locating hidden defects.

IRON AND STEEL

CORROSION. Study of the Resistance of Overstressed Wrought irons and Carbon Steels to Salt-water Corrosion, J. N. Friend. *Iron and Steel Inst. (Lond.), Advance Paper*, no. 4, May 1928, 12 pp., 4 figs.

Corrodibility of wrought iron in salt water is not enhanced by stretching even to rupture, by twisting, or by compression up to 30 per cent; corrodibility of carbon steels is not enhanced by stretching; torsion and compression within range described does not affect appreciably rate of corrosion of 0.11 per cent carbon steel in salt water; torsion and compression increase slightly corrodibility of 0.20 per cent carbon steel.

CORROSION. Report of Committee A-5 on Corrosion of Iron and Steel. *Am. Soc. Testing Matls.—Preprint*, no. 13, for mtg. June 25, 1928, 34 pp.

Sub-committee no. 3 on Inspection of Fort Sheridan and Annapolis Tests reports additional failures and presents extension of tables giving results for various sheets grouped as regarding presence of copper.

OXYGEN DETERMINATION. Effect of Oxygen on the Structure of Iron and Steel, P. Oberhoffer, H. J. Schiffler and W. Hessenbruch. *Iron and Steel World*, vol. 2, no. 4, Apr. 1928, pp. 221-222.

In regard to influence of oxygen on primary and secondary structure of iron and steel, in numerous vacuum meltings distinct segregation of crystals was observable after first etching; it was attributed to oxygen present in solid solution; same phenomena in regard to primary etchings were proved in series of alloy steels. From report of Committee for Working Materials of German Iron and Steel Inst.

IRON-CHROMIUM ALLOYS

STRUCTURES. On the Structure of the Iron-Chromium-Carbon System, A. Westgren, G. Phragmen and T. Negresco. *Iron and Steel Inst. (Lond.),—Advance Paper*, no. 16, May 1928, 18 pp., 6 figs.

X-ray analysis of iron-chromium alloys has proved that these metals form unbroken series of solid solutions; on basis of data obtained, equilibrium diagram of iron-chromium-carbon system has been drawn; photomicrographs; bibliography.

MAGNESIUM ALLOYS

Electron (Elektronmetall). *Zeit. fuer die Giessereipraxis (Berlin)*, vol. 49, no. 20, May 13, 1928, (Metall), p. 79.

Tests are being carried out on electron

metal, which is light alloy of magnesium (80 to 95 per cent) and aluminum, produced by I. G. Farbenindustrie; this metal is 40 per cent lighter than other aluminum alloys in use, but is said to possess equal strength; its use in automobile and aircraft construction.

MALLEABLE IRON

Malleablizing Hard Iron in Tunnel Kilns, J. H. Hruska. *Fuel and Furnaces*, vol. 6, no. 5, May 1928, pp. 611-612, 2 figs.

Malleablizing of hard iron is function of chemical analysis, time and temperature conditions and quite often also of thickness or design of castings to be treated; conditions under which good quality of malleable iron can be produced are shown in diagrammatic form.

MANGANESE STEEL

TESTING. Wearing Tests of Twelve-per cent Manganese Steel, J. H. Hall. *Am. Soc. Testing Matls.—Preprint*, no. 32, for mtg. June 25, 1928, 6 pp., 1 fig.

Development of test for wearing properties of 12 per cent manganese steel that will give results comparable with service experience by crushing known amounts of hard stone in small laboratory stone crusher, jaws of which were made of steel to be tested; loss in weight of jaws was determined at regular intervals; details of tests in such crusher of manganese steel, plain carbon steel, nickel steel, chromium steel, and nickel-chromium steel.

MATERIALS

X-RAY ANALYSIS. Analysis of Minerals, Ores and Industrial Products by Means of X-Rays (La détermination à l'aide des rayons X des minéraux, minérais et de quelques produits industriels), R. van Aubel. *Revue de l'Industrie Minérale (Paris)*, no. 177, May 1, 1928, pp. 189-195, 8 figs.

Qualitative analysis, how made; identification, minerals; alloys, colloidal materials; ceramic products. Bibliography. (Concluded.)

METAL-WORKING TOOLS

CHROMIUM-PLATED. Chromium-plated Metal-working Tools. *Machy. (Lond.)*, vol. 32, no. 816, May 31, 1928, pp. 257-258, 2 figs.

Hardness of chromium plate; chromium-plated cutting tools and dies show greatly increased resistance to wear; building up worn plug gages; cleaning work to be plated; electric-current requirements; cost of chromium plating.

METALS

COLORING. Metal Coloring and Decorating, N. Hepburn. *Brass World*, vol. 24, no. 5, May 1928, pp. 151-152, 2 figs.

Study of patina, its use and abuse; preparing iron fixtures for outdoor purposes; preparing ingot tin for hot tinning process; preparing tinning flux; tinning object; method of applying paint; preparing brass lantern for antique effect.

CORROSION. Influence of Corrosion Accelerators and Inhibitors on Fatigue of Ferrous Metals, F. N. Speller, I. B. McCorkle and P. F. Mummer. *Am. Soc. Testing Matls. —Preprint*, no. 42, for mtg. June 25, 1928,

9 pp., 3 figs.

This paper compares ordinary corrosion fatigue with respect to factors involved, many of which are common to both cases; experiments are described showing effect of inhibitors on corrosion-fatigue with and without other external influences tending to accelerate corrosion; tends to increase useful life of metal under fatigue by slowing up action of localized corrosion; further experimental work is planned.

CORROSION. The Application of Electric Resistance Measurements to Study of the Atmospheric Corrosion of Metals, J. C. Hudson. *Phys. Soc.—Proc. (Lond.)*, vol. 40, part 3, Apr. 15, 1928, pp. 107-131, 9 figs.

Describes experimental procedure for quantitative field tests on atmospheric corrosion of metals which is based on determination of change in electric-resistance changes produced on exposure; method is capable of great accuracy and resistance changes produced in duplicate specimens agree to within 5 per cent.

CORROSION. Relative Corrodibilities of Ferrous and Nonferrous Metals and Alloys, J. N. Friend. *Metal Industry (Lond.)*, vol. 32, no. 18, May 4, 1928, pp. 449-453.

Results of four years' exposure in Bristol Channel; 50 bars of ferrous and nonferrous metals were exposed to sea action and account is given of 14 nonferrous bars; losses in weight, depths of pitting, reduction in diameter, and fall in tensile strength in consequence of corrosion are correlated; metals examined included tin, lead, nickel, zinc, aluminum, and various coppers and brasses; nickels, tin-lead resisted corrosion remarkably well.

CORROSION. Relative Corrodibilities of Ferrous and Nonferrous Metals and Alloys, J. N. Friend. *Metal Industry (Lond.)*, vol. 32, no. 21, May 25, 1928, pp. 522-625.

Results of four years' exposure in Bristol Channel; 50 bars of ferrous and nonferrous aluminum in marine engineering; beneficial effect of nickel; selective corrosion of Muntz metal; important influence of physical condition; lead inferior to zinc; arsenic in copper. (Concluded.)

CORROSION RESISTANCE. Acid-Proof Metals and Alloys (Saeurefeste Metalle und Legierungen), W. R. Hanau. *Korrosion und Metallschutz (Berlin)*, vol. 4, no. 3, Mar. 1928, pp. 49-53, 6 figs.

Qualitative classification of metals and alloys on basis of their resistance to acid corrosion; results of tests of number of ferrous alloys, nickel and iron. Paper presented at Werkstofftagung, Berlin, 1927.

METALLURGY

DEVELOPMENTS. Present Trends in Metallurgy, L. O. Howard. *Can. Min. Jl. (Gardenvale, Que.)*, vol. 49, nos. 18 and 19, May 4 and 11, 1928, pp. 370-372 and 386-389, 4 figs.

May 4: Metallurgy of principal nonferrous metals; trend toward higher-grade concentrate containing more copper, and less iron and silica; direct smelting of wet unroasted concentrate in reverberatory furnaces; smelting copper concentrate in converters; utilization of iron in copper ore; decided trend toward wet methods; in metallurgy of lead, selective flotation is having considerable effect. May 11: Metallurgy of zinc, gold and silver.

MOLYBDENUM STEEL

Molybdenum Steels (les aciers au molyb-
dene). *Jl. du Four Electrique (Paris)*, vol.
37, no. 5, May 1928, pp. 148-149.
Influence of molybdenum ; analyses, uses
and manufacture.

NICKEL-IRON ALLOYS

PERMALLOY. Compressed Powdered Perm-
alloy Manufacture and Magnetic Properties,
W. J. Shackelton and I. G. Barber. *Am.
Inst. Elec. Engrs.—Jl.*, vol. 47, no. 6, June
1928, pp. 437-440, 7 figs.
Description of manufacture of magnetic
cores of compressed permalloy powder fol-
lowed by information covering their mag-
netic properties with particular reference to
their use in loading coils ; production of
powder, and its insulation, pressing and
annealing ; permeability, core loss, and modu-
lation are treated.

NICKEL STEEL

PROPERTIES. The Properties of Nickel
Steels, With Special Reference to the Influ-
ence of Manganese, J. A. Jones. *Iron and
Steel Inst. (Lond.)—Advance Paper*, no. 8,
May 1928, 36 pp., 20 figs.
Steels containing carbon 0.2 to 0.55 per
cent and nickel 3 to 12 per cent were ex-
amined ; with low manganese content there
is no advantage in increasing nickel beyond
6 per cent ; effect of manganese up to 0.8
per cent is small ; manganese has marked
influence on mass effect in 3 to 4 per cent
nickel steel ; bibliography. See Iron &
Coal Trades Rev., vol. 116, no. 3141, May
11, 1928, p. 706, and Foundry Trade Jl.,
vol., 38, no. 613, May 17, 1928, p. 362.

NONFERROUS METALS

SPECIFICATIONS. Report of Committee
B-2 on Nonferrous Metals and Alloys. *Am.
Soc. Testing Matls.—Preprint*, no. 18, for
mtg. June 25, 1928, 50 pp.
Report of sub-committee on die-cast metals
and alloys ; proposed tentative specifications
for copper products, silver solder, and brass
ingot metal.

PICKLING METALS

The Electrochemical Action of Inhibitors
in the Acid Solution of Steel and Iron, E.
L. Chappell, B. E. Roetheli, and B. Y. Mc-
Carthy. *Indus. and Eng. Chem.*, vol. 20,
no. 6, June 1928, pp. 582-587, 17 figs.
Pickling of steel or iron consists in re-
moval of surface scale by immersion in
acid ; addition of inhibitors to acid greatly
decreases rate of attack on bare metal, but
at same time permits fairly rapid solution
of scale ; it is suggested that inhibitive ac-
tion is due to formation of layer of dis-
charged inhibitor substance on cathode areas.
Bibliography.

RAILS

MANUFACTURE (KRUPP PRACTICE).
Manufacture of Rails in Germany, C. W.
Gennett. *Metallurgist (supp. to Engineer,
Lond.)*, May 25, 1928, pp. 76-77.
Rails rolled at Krupp Works for American
railroad company ; details of manufacture
and testing are described, drawing attention

to two departures from American practice ;
no "X-Rays" were produced, for which cred-
it is given to bottom pouring ; other out-
standing feature is method of straightening ;
no hot cambering machine was used.

TRANSVERSE FISSURES. Surface Cracks
of Rails in Service (A propos de la fissuration
superficielle des rails en service), Sabouret.
Revue de Métallurgie (Paris), vol. 25, no.
3, Mar. 1928, pp. 169-171.
Discussion of study by H. Viteaux, stat-
ing experiences with rails and tests made ;
also author's reply.

SHEET METAL

CLEANING. Cleaning Sheet Metal to be
Finished, G. E. Heron. *Indus. Finishing*,
vol. 4, no. 7, May 1928, pp. 107-108 and
110.
Troubles caused by improper cleaning of
metal surfaces ; explains specifically how to
keep cleaning solutions and rinses in first-
class condition and points out why this is all-
important.

SHEET STEEL

MANUFACTURE—GERMANY. The Manu-
facture of Thin Sheet for Special Uses (Die
Herstellung von Feinblechen fuer Sonder-
zwecke), W. Kraemer. *V. D. I. Zeit. (Ber-
lin)*, vol. 72, no. 22, June 2, 1928, pp.
725-733, 20 figs.
Manufacturing procedure for hot-rolled and
cold-rolled thin sheets ; description of Demag
and Krupp thin sheet mills and other man-
ufacturing equipment ; tests and specifica-
tions.

SIICON FERRITE

ANNEALING. Effect of Ageing on Cold-
Worked Single Crystals of Silicon-Ferrite,
H. O'Neill. *Iron and Steel World*, vol. 2, no.
4, Apr. 1928, p. 222.
Results of scratch hardness tests to deter-
mine distribution of strain hardness fol-
lowed by annealing and effect of ageing
on cold-worked crystals of silicon-ferrite.
Paper read before Am. Inst. Min. and Met.
Engrs.

SILICON STEEL

BRIDGES. Silicon Structural Steel for
Bridge Construction, H. T. Morris. *Am.
Soc. Steel Treating—Trans.*, vol. 13, no. 6,
June 1928, pp. 954-960.
Problems connected with production of sil-
icon steel used in towers of Philadelphia-
Camden Bridge ; higher elastic-limit steel
specified for 70 per cent of rolled structural
material in these towers, total weight of
which is 10,000 tons, was type of silicon
steel which had been previously occasionally
used for span bridges ; this steel consisted of
riveted members composed of plates and
angles ; plates were rolled directly from
bottom-poured soaking-pit heated ingots ; all
angles were rolled from blooms reheated in
gas-fired continuous furnace feeding struc-
tural mill.

SILVER

HEAT TREATMENT. Effect of Heat
Treatment on Mechanical Properties of Stand-
ard Silver. *Fuel and Furnaces*, vol. 6, no.
5, May 1928, p. 678.
Description of salt bath ; method of tem-
pering ; results obtained.

SPRINGS

MANUFACTURE. Modern Methods in Our Workshops, C. J. Graham. *New Zealand Ry. Mag. (Wellington)*, vol. 2, no. 12, Apr. 1, 1928, pp. 38-40, 7 figs.

New spring plant at Hillside; treatment of springs; cropping, nibbing and trimming; forming; quenching; drawing; assembling; testing; control of temperature.

SPRING STEEL

BRITTLENESS TESTING. Measurement of Brittleness, P. L. Irwin. *Am. Soc. Testing Matls.—Reprint*, no. 95, for mtg. June 25, 1928, 8 pp., 6 figs.

Author contends that flexure test, recommended by earlier investigators, is better type of test from theoretical as well as experimental standpoint, than tension test usually employed; results of brittleness tests on thin spring steel, which has been embrittled by electrolytic cleaning, are given which show effect of duration of treatment, current density, and time and temperature recuperation.

STAINLESS STEEL

The A-B-C of Corrosion Resisting Steels, F. R. Palmer. *Iron and Steel (Gardenvale, Que.)*, vol. 11, no. 5, May 1928, p. 144.

Fundamentals that will greatly assist consumer in investigating metals themselves and their fields of application; general properties of each group of stainless steels, briefly tabulated without attempt to extend table beyond mere delineation of group characteristics.

JOINING. Soldering, Brazing, and Welding Stainless Steels. *Mech. World (Manchester, Eng.)*, vol. 83, no. 2157, May 4, 1928, pp. 322-323.

Writer deals with processes of soldering, brazing, and welding these steels for modern requirements; soft-soldering stainless steels; soldering fluxes. (To be continued.)

WELDING. Welding Corrosion Resisting Steel Alloys, W. B. Miller. *Am. Welding Soc.—Jl.*, vol. 7, no. 5, May 1928, pp. 49-59, 15 figs.

Brief description of more common groups according to their composition and more generally accepted group names and welding procedure for given group; tensile properties of sheet and welds before and after annealing were determined.

STEEL

ANNEALING. The Constitution of Steel and Cast Iron, F. T. Sisco. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 6, June 1928, pp. 1043-1057, 12 figs.

Discusses variations usually included under description of annealing; most important item is annealing below critical range used extensively for cold-worked steel products such as wire, sheet, tubular, products and the like; also annealing of alloy steels, patenting of wire, annealing of steel castings and graphitization of malleable iron.

CARBURIZING. Studies on Normal and Abnormal Carburizing Steels, O. E. Harder, L. J. Weber and T. E. Jerabek. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 6, June 1928, pp 961-962 and discussion 992-1008, 36 figs.

Studies on carburizing steels under following headings: effect of heating abnormal steels in vacuo at carburizing temperatures; effect of heating normal steels in nitrogen, oxygen, and carbon dioxide; effect of melting steels in vacuo in alundum and magnesite crucibles; effects of melting normal steels in contact with sonims; X-ray examination by powder method; mechanism is proposed for formation of structure found in abnormal carburizing steels.

COLD WORKING. Strength and Endurance of Cold Drawn Mild Steel, R. M. Brown. *Metallurgist (supp. to Engineer, Lond.)*, May 25, 1928, pp. 75-76.

Investigation was confined to mild steel which had been moderately cold worked by drawing through dies, but author considers that other methods of cold working would probably produce similar effects; magnitude of internal stress was reduced as severity of cold work was increased, and maximum tensile strength did not occur at skin in case of most severely worked specimen. Abstract of paper read before Instn. Engrs. and Shipbldrs. in Scotland.

FLOW TESTING. "Long-Time" or "Flow" Tests of Carbon Steels at Various Temperatures with Particular Reference to Stresses Below the Proportional Limit, J. J. Kanter and L. W. Spring. *Am. Soc. Testing Matls.—Preprint*, no. 35, for mtg. June 25, 1928, 27 pp., 20 figs.

Much thought and discussion have been given to meaning of this phenomenon; since making of "long-time" high-temperature or "flow" tests is quite time-consuming, some method of determining, or factor for estimating, rate of flow at different stresses has been sought by investigators, but, seemingly, no satisfactory short-time method of estimation has yet been found.

HEAT TREATMENT. Heat Treating Educational Conference. *Iron Age*, vol. 121, no. 20, May 17, 1928, pp. 1409 and 1429.

Review of second Annual Conference on Steel Treating; methods of steel production, application of special steels and their heat treatment discussed; papers on carburizers, stainless steels and fatigue; problems connected with carburizers; electricity for heating; preventing carbon penetration; some new stainless alloys; new alloys developed by Krupp; nickel, chromium and molybdenum as alloys.

HEAT TREATMENT — TEMPERATURE CONTROL. The Control of Temperature in Heat Treating, G. C. Davis. *Mech. World (Manchester)*, vol. 83, no. 2161, June 1, 1928, pp. 356-396.

Final temperature of work being heated is discussed; in usual practice in heat treating high speed steel it is impossible to have tool ever reach final temperature of furnace; great deal has been done lately in improvement of heating of carbon-steel tools; growing use of liquids for heating.

LOW-CARBON — TESTING. Flow in a Low-Carbon Steel at Various Temperatures, French and Tucker. *Can. Machy. (Toronto)*, vol. 39, no. 11, May 31, 1928, p. 31.

Discussion of Bureau of Standards paper giving account of investigation of flow of low-carbon steel at various temperatures; relation between load and life; one of principal effects of increase of temperature is reduction of strain-hardening ability of steel.

MANUFACTURE — ELECTRIC PROCESS. Electric Steel Manufacture, F. T. Sisco.

Fuels and Furnaces, vol. 6, no. 5, May 1928, pp. 589-600.

Discussion of types of furnaces and different processes used in manufacture of electric steel; divisions of electric steel manufacture; oxidation period; control of oxidation in melting; deoxidizing slag; reactions of deoxidization; desulphurization; degasification; acid-furnace practice.

MACHINABILITY. Machinability of Steel, A. H. d'Arcambal. *Iron Age,* vol. 121, no. 22, May 31, 1928, p. 1541.

Machine-tool equipment used; quality of metal-cutting tools employed; type of material being machined; cutting fluid or coolant used; human element; sulphur-base coolant used on most jobs. Abstract of paper presented at Am. Soc. Steel Treating.

MOLTEN—OCCLUDED GASES. A Study of Gases Occluded in Molten Steel (Ein studie over gaser i flytande stal), E. Ameen and H. Willners. *Jernkoftorets Annaler* (*Stockholm*), vol. 83, no. 4, 1928, pp. 195-265, 24 figs.

History of earlier methods and exhaustive report on original experiments made to ascertain occurrence of gases, to effect their removal and to improve on apparatus hitherto used therefor; formulas and results of analyses made. Bibliography.

OVERSTRAINED — NORMALIZING. The Rapid Normalizing of Overstrained Steel, W. E. Woodward. *Engineering* (*Lond.*), vol. 125, no. 3255, June 1, 1928, pp. 682-684, 3 figs.

Discusses normalization by direct and by alternating currents. Abstract of paper read before Iron and Steel Inst., previously annotated.

PROPERTIES. The Physical and Mechanical Properties of Steels, Their Significance and Their Relations, G. E. Troxell. *West. Machy. World,* vol. 19, no. 5, May 1928, pp. 205-206, 5 figs.

Discussion of principal factors influencing properties of steel.

PROPERTIES. Steel Practice Determines Quality, H. D. Hibbard. *Iron and Steel Can.* (*Gardenvale, Que.*), vol. 11, no. 6, June 1928, pp. 177-178.

How given element or impurity may affect properties of steel in various ways depending upon its origin; influence of elements; all insolubles are harmful to steel; manganese important at end; silicon is medicine for steel.

TEMEPERATURE EFFECT. The Strength of Steel at Elevated Temperatures With Particular Reference to Safety Factors, T. McL. Jasper. *Am. Petroleum Inst.—Bul.,* vol. 9, no. 7, Jan. 31, 1928, pp. 166-172 and (discussion), 172-173, 4 figs.

At elevated temperatures short-time test values of steel vary very materially from long-time test values; ordinary steel used in construction of pressure containers has yield point which is very pronounced; corrosion as factor in design; strength of steel under elevated temperatures. Bibliography.

TEMPERATURE EFFECT. Steel at High Superheat Temperatures. *Machy.* (*Lond.*), vol. 32, no. 814, May 17, 1928, p. 216.

Information on temperature strength curves for various kinds of steel; with larger additions of alloying elements very definite improvement in ability to retain strength at high temperatures is effected.

STEEL CASTINGS

HEAT TREATMENT. Milwaukee Plant Heat Treats Miscellaneous Steel Castings, A. W. Lorens. *Foundry,* vol. 56, no. 11, June 1, 1928, pp. 453-456, 7 figs.

Description of heat treating plant of Bucyrus-Erie Co. equipped to handle 1000 to 1500 tons of steel castings per month; heating equipment consists of four box-type electric furnaces; handling equipment.

HEAT TREATMENT. How a Milwaukee Plant Heat Treats Miscellaneous Steel Castings, A. W. Lorenz. *Iron Trade Rev.,* vol. 82, no. 20, May 17, 1928, pp. 1269-1272, 7 figs.

Experience of Bucyrus-Erie Co. with heat treated steel castings; one-third of foundry's output is quenched and tempered in electrically heated furnaces having novel charging devices; furnaces and equipment used; loading racks; entire cycle, including opening of doors, handled by one man on platform of charging machine.

TESTING. Physical Test Specimens from Commercial Steel Castings. *Research Group News,* vol. 5, no. 1, Apr. 1928, pp. 175-180, 2 figs.

Conditions effecting physical properties; susceptibility of all metals to manufacturing processes; how material in steel castings should be listed; data from tests of unsuitable specimens; dependability of metal parts despite poor tests from certain sections; importance of design.

STEEL FOUNDRY PRACTICE

Problems in Steel Founding (Die Beantwortung einiger Fragen aus dem Gebiete des Stahlformgusses), B. Osann. *Giesserei,* (*Duesseldorf*), vol. 15, no. 20, May 18, 1928, pp. 466-468.

Discussion is in form of answers to questions asked of author on occasion of his visits to different foundries.

Unexpected Variations Dominate Steel Casting Practice, F. A. Melmoth. *Foundry,* vol. 56, no. 11, June 1, 1928, pp. 443-446.

Factors influencing products of steel castings are human element, influence of various molding operations, metallurgical behavior of steel in sand casting; British practice discussed. Paper presented at Am. Foundrymen's Assn. (To be continued.)

Effect of Heat Treatment on Steel Castings, F. A. Melmoth. *Fuels and Furnaces,* vol. 6, no. 6, June 1928, pp. 787-790.

Discussion of various heat treatments of steel castings and precautions to be observed to produce desired grain structure, and to avoid defects attributable to incorrect manipulation during heat treatment; straight annealing; stress in castings as received from mold; liability of fracture from uneven heat treating. Abstract of paper presented at Am. Foundrymen's Assn.

CASTING TEMPERATURE. Casting Temperature and Speed (Ueber Giesstemperature und Giessgeschwindigkeit), F. Beitter. *Stahl u. Eisen* (*Duesseldorf*), vol. 48, no. 18, May 3, 1928, pp. 577-583 and (discussion) 583-585, 11 figs.

Points out that casting temperature is in close relationship with casting speed; determination of melting temperature in furnace;

cooling of steel to proper casting temperature; temperature drop of steel while in ladle; control of casting speed.

STRAIN GAGES

New Maihak Acoustical Strain Gage. *Instruments*, vol. 1, no. 5, May 1928, pp. 251-252, 2 figs.

Designed to measure strain and accompanying stress induced in machine parts (flywheels, propeller shafts), steel structures, foundations, bridges, etc., acted upon by live loads or superimposed loads and dynamic forces.

STRUCTURAL STEEL

BRIDGES. High-Strength Steel for Modern Bridges, L. S. Moisseiff. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 6, June 1928, pp. 941-949.

Indications of trend in bridge building and brief history of use of alloy steels; use of nickel steel for bridges; heat treated steel in bridge building.

ELECTRIC WELDING. Latest Advances in Electric Welding Construction, H. E. Grove. *Australian Elec. Times (Melbourne)*, vol. 7, no. 4, Apr. 27, 1928, pp. 313-314, 1 fig.

Account of how electric welding aids construction department; coke-handling plant, entirely designed, fabricated, and erected by construction department; traveling bridge merits special mention; all-welded steel gas purifier has also been installed.

PROPERTIES. Factors of Safety and Quality of Material, W. H. Riddlesworth. *Shipbldr. (Newcastle-on-Tyne)*, vol. 35, no. 213, May 1928, pp. 307-309.

What is meant by factor of safety; attempt is made in table to indicate peculiar strength quality or property of material upon which failure depends, for each elementary structural part and for each mode of failure. Paper read before Instn. Engrs. & Shipbldrs. in Scotland.

TESTING. Tests of Specimens Cut from Different Portions of Structural Steel Shapes. M. O. Withey. *Am. Soc. Testing Matls.—Preprint*, no. 29, for mtg. June 25, 1928, 14 pp.

Data from 386 tension and compression tests of specimens cut from parts of shapes used in recent column tests made for Am. Soc. of Civil Engrs. are presented; modulus of elasticity was nearly constant; tensile strength was uniform for specimens taken from given shape, but ranged for different shapes about 22 per cent; average yield point for different shapes exhibited spread of 33 per cent both in tension and in compression.

TOOL STEEL

Some Notes on Tool Steels, A. L. Walker. *Cassier's Indus. Mgmt. (Lond.)*, vol. 15, no. 5, May 1928, pp. 179-180.

Property and uses of more common steels used in toolroom, including high carbon, tungsten, manganese, tungsten vanadium, chromium-vanadium, cobalt-chromium, and nickel-chromium-alloy.

TOOLS

BENDING AND FORMING. Bending and Forming Tools, W. Richards. *Mech. World (Manchester, Eng.)*, vol. 83, nos. 2157 and 2159, May 4 and 18, 1928, pp. 325-326 and 360-362, 6 figs.

May 4: Forming operations frequently performed in combined forming and blanking tools; example of combined forming and blanking tool design is given. May 18: Combination piercing, cutting off, and forming tool. (To be continued.)

HIGH SPEED—TESTING. Endurance of High Speed Cut-off Tools in Relation to Magnetic and Other Measurements, H. Styri. *Am. Soc. Testing Matls.—Reprint*, no. 30, for mtg. June 25, 1928, 10 pp.

Number of standard cut-off tools hardened in groups from different temperatures have been used in cutting off rings of high-carbon chromium steel having Brinell hardness of about 180; magnetic and electric tests, and Rockwell hardness and duroscope readings were made on these tools, and relation between these values and number of rings cut per grind are shown; methods of measurement are described and possible reasons for irregularities in results are indicated.

METAL CUTTING. New High-Speed Cutting-Tool Metals Interest British Metal Workers. *Am. Mach.*, vol. 68, no. 21, May 24, 1928, p. 868b.

Some records established by German and English products; metal cutting at unusually high speeds shown at recent Leipzig Fair; in Great Britain, new material B. V. introduced which can be heat treated and machined in much the same manner as ordinary 18 per cent tungsten high speed steel.

METAL CUTTING — CHROMIUM PLATING. Chromium-plating Metal-working Tools, P. Cattucci. *Machy. (N. Y.)*, vol. 34, no. 10, June 1928, pp. 764-766, 2 figs.

Hardness of chromium plate; chromium-plated cutting tools show greatly increased resistance to wear; dies and metal-spinning tools; building up worn plug gages; experience is necessary factor; cleaning work to be plated; electric-current requirements; cost of chromium plating.

TUNGSTEN STEEL

MAGNET. Effect of Silicon on Tungsten Magnet Steel, J. Swan. *Iron and Coal Trades Rev. (Lond.)*, vol. 116, no. 3140, May 4, 1928, pp. 656-657.

Preliminary experiments; effect of silicon on formation of tungsten carbide; theoretical considerations; summary and conclusions. Abstract of paper read at Iron and Steel Inst.

WIRE, STEEL

HEAT TREATMENT. Drawn Wire and Its Heat Treatment, A. V. deForest. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 6, June 1928, pp. 952-954, 1 fig.

Use of hard-drawn galvanized wire; for Hudson river bridge, attempts were made to improve this product by further improving strength of hard-drawn bright wire before galvanizing; another system of wire making has been developed for bridge work which shows marked improvement; instead of wire hardened by cold working, fully heat treated steel was used in quenched and tempered state.

News of the Chapters

THE membership standing of the society as of July 1, 1928, is as follows:

GROUP I		GROUP II		GROUP III	
1. Detroit	448	1. Los Angeles	149	1. New Haven	92
2. Chicago	429	2. Hartford	138	2. Tri City	70
3. Pittsburgh	350	3. Golden Gate	120	3. Washington	69
4. Philadelphia	309	4. Lehigh Valley	116	4. Worcester	68
5. New York	301	5. Milwaukee	114	5. Rockford	58
6. Cleveland	289	6. Cincinnati	102	6. Providence	56
7. Boston	248	7. St. Louis	100	7. Rochester	54
		8. Indianapolis	91	8. Southern Tier	53
		9. Dayton	89	9. Toronto	48
		10. Syracuse	84	10. Columbus	46
		11. Canton-Mass.	83	11. Schenectady	42
		12. Buffalo	75	12. Springfield	37
		13. Montreal	68	13. Fort Wayne	27
		14. North-West	55	14. Notre Dame	22

GROUP I—The seven chapters in this group maintained their same positions as last month excepting that New York passed Cleveland, advancing from sixth to fifth place.

GROUP II—Los Angeles still holds the lead in Group II with eleven members more than Hartford. While none of the chapters in this group showed a gain, some of them showed smaller losses and consequently there has been quite a rearrangement of their standings. Cincinnati advanced from ninth to sixth place; St. Louis from eighth to seventh place; Indianapolis from tenth to eighth and Syracuse from eleventh to tenth place. Canton-Massillon dropped from sixth to eleventh; and Dayton from seventh to ninth.

GROUP III—All chapters in this group with the exception of Rochester and Providence showed a loss numbering from eleven to one. New Haven still heads the group with ninety-two members; Tri City advanced from fourth to second place; Rochester from ninth to seventh place; Toronto from tenth to ninth; while Washington dropped from second to third place; Worcester from third to fourth; Southern Tier from sixth to eighth; and Columbus from eighth to tenth place.

GOLDEN GATE CHAPTER

The June dinner meeting of the Golden Gate Chapter was held on the evening of June 13, at the Engineer's Club, San Francisco. Dr. W. J. Crook and C. E. Williams, chairman and vice-chairman respectively of

the section, were unavoidably absent. Mr. C. S. Alexander, our vice-chairman for the preceding year, kindly consented to preside.

The various chairmen were asked to report upon the activities of their committees. H. J. Barton, who was visiting us from the Los Angeles section, outlined the progress which is being made in the plans for the Metal Conference in January, and urged the necessity of prompt reservation of space by those intending to exhibit.

After discussion of the Committee reports, E. E. Fess delivered an interesting talk upon commercial brasses and bronzes, indicating the common characteristics, physical properties, chemical analyses and allowable tolerances of the common alloys. This paper was productive of a good deal of discussion, which continued through the showing of the five-reel film entitled ''The Story of Copper'' which followed.

''The Story of Copper'' proved to be one of the recently made and interesting educational films issued by the Bureau of Mines, Salt Lake City, Utah. It covered the three phases of copper production, viz., smelting, refining and fabrication, and filled out an evening's discussion on entirely nonferrous subjects. The Chapter is indebted to Mr. Fess, speaker of the evening, the Bureau of Mines for the film, and to W. P. Brown, a member of our Chapter, who kindly loaned the moving picture machine, and to L. J. Miller, of the E. H. Edwards Company, who operated it.

H. E. Morse.

LOS ANGELES CHAPTER

The June meeting of Los Angeles Chapter of the American Society for Steel Treating was held Thursday evening, June 7. We were very fortunate in being allowed the privilege of meeting again at the Frank Wiggins Grade School, and enjoyed very greatly the excellent dinner served us by the students.

After the splendid dinner Mr. Harington introduced the speaker of the evening, G. Sauppe, of Spindler and Sauppe. Mr. Sauppe spoke on the subject, ''Microscopic Equipment''. His talk was very interesting and he was kind enough to bring with him many pieces of microscopic equipment. Following Mr. Sauppe's talk, he demonstrated to the members many features of modern microscopic equipment.

Professor W. Howard Clapp brought with him some etched and unetched pieces of steel. These were all studied and Mr. Clapp explained to us just what we saw revealed in the microscope. We all enjoyed this privilege greatly.

The meeting was adjourned about ten o'clock and all members reported as having had a very interesting and instructive evening.

There were again several memberships brought into the meeting which will help maintain the performance of Los Angeles Chapter.

H. V. Ruth.

ST. LOUIS CHAPTER

The first annual barbecue and stag picnic of the St. Louis Chapter

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Louis Chapter

was held at Bellville, Illinois, Reiths Farm, Saturday, June 23, 1928, with about two hundred and fifty members and guests present. Sports such as base ball, cork ball, tug of war, fat men's race, horse shoes, etc., were enjoyed by all.

The location was ideal and it was indeed a joy to watch these technical men get back to their boyhood days and away from the old time stuff and technical meetings that are generally thought of in our every day work of our chosen field.

The writer has had the pleasure of not having heard of one complaint, as everyone who attended this frolic has asked to have it made a monthly affair and not yearly. Of course this is impossible from the treasurer's standpoint and I am sure one glance at the treasury and the boys would change their minds. The frolic committee is certainly to be congratulated for its able handling of this frolic, but the secretary has writer's cramp from paying the bills and the treasurer has a deficit that the membership committee will have to hump to make up for the nice showing we had in the past year, however, all in all it was one of the most successful and enjoyable affairs the A. S. S. T. has ever known in the St. Louis Chapter, and the writer feels sure that the money was well spent and the occasion will more than bring in enough cash in new members to offset the deficit.

Motion pictures were made of this meeting and stag and the members will have a chance to see themselves as others do, we can assure you there were Doug. Fairbanks and Harold Lloyds that will enjoy seeing themselves.

This closed the St. Louis Chapter's season and there will be no more meetings until September.

One of the sad things to report is the death of Robert Hickey, chief mechanical engineer of the Century Electric Co. We know he will be a loss to his company and the St. Louis Chapter has lost a member that is to be regretted, as Mr. Hickey was just begining to take a great interest in our society and the writer feels his loss very keenly.

Carl G. Werscheid.

WASHINGTON-BALTIMORE CHAPTER

The final meeting of the year was held on May 11 as a joint meeting with the American Institute of Mining and Metallurgical Engineers—being the second joint meeting.

A dinner was held before the meeting at the Cosmos Club at which many out of town guests were present, the meeting having been scheduled to coincide with the annual meetings of the Metallurgical Advisory Committee to the Bureau of Standards.

Following the dinner, Dr. G. K. Burgess, director of the Bureau of Standards, gave a short informal talk on the organization of the Bureau with particular reference to the Commercial Standards Group.

The meeting then adjourned to the auditorium of the Interior Building to hear the speaker of the evening, Dr. Mathewson, of Yale University, who gave a very interesting talk covering recent studies he has made on Neumann

bands of ferrite. Starting from an elementary discussion of the lattice structure of metals he pointed out the importance of the 1 1 2 planes with particular reference to slip and twinning movements. Considerable credit was given to the earlier German work of Mügge whose work was confirmed in proving he believed without qualification that Neumann bands are mechanical twins. The earlier work lacked the precision of measurement possible at the present time. The talk was illustrated by models and slides.

Before the lecture, a brief business meeting was held to hear the reports of the various committees, all of which were approved. The following officers were elected for the ensuing year: Chairman—Harry K. Herschman, Washington; Vice Chairman—George Nauss, Baltimore; Secretary-Treasurer, J. E. Crown, Washington; Chairman—Meetings Committee—H. S. Rawdon, Washington; Secretary of Meetings—W. R. Angell and A. I. Krynitsky. The Executive Committee, in addition to officers, is composed of the following: W. R. Angell, G. W. Quick, L. H. Fawcett, J. W. Barnett and Emil Gathmann.

J. R. Freeman.

We are indeed sorry to record the death of V. S. Yarnall, a well known member of the society and member of the Boston Chapter.

Mr. Yarnall was associated with the Phoenix Iron Co., Carnegie Steel Co., Ludlum Steel Co., and the Ames Shovel and Tool Co. He died at the age of 62 years. All of his life he had been an ardent and enthusiastic worker in the fabrication and use of steel in all its various phases and uses.

Items of Interest

THE Colonial Steel Co., announces the opening of a new warehouse at 712-714 Cass Ave., St. Louis. Charles V. Franklyn is district manager and Carl G. Werscheid, assistant district manager. An invitation is extended to inspect the new warehouse where a complete stock of high speed and carbon tool steels, hollow and solid drill rods is maintained.

Pamphlet 1129 has recently been issued by E. Leitz, 60 E. 10th St., New York, describing the new universal chemical microscope. With the addition of essential accessories, this microscope is equally well adapted for bacteriological, biological and metallurgical work.

The International Nickel Co., New York, has issued a bulletin containing data on wear and machinability of cast iron alloyed with nickel. The text is illustrated with photomicrographs of sections of cast iron.

The Brown Instrument Co., Philadelphia, has recently started another addition to its plant. The new building is to provide research facilities commensurate with the widening application of its products.

"Oil Field Welding" is the title of a handbook on acetylene and arc welding recently issued by the Stoody Co., Whittier, Calif. This book covers the development of hard facing in the oil industry, the use of hard facing metals in the reclamation of tools and drilling equipment. The methods of applying hard facings by means of welding are described. This book may be obtained by addressing a request to the above company.

Dr. J. M. Lohr, formerly in charge of melting for the Hoskins Mfg. Co., Detroit, is now plant metallurgist for the Driver-Harris Co., Harrison, N. J.

Dr. John Johnston, director of research and technology of the United States Steel Corp., C. A. Reinhardt, chief metallurgist of the Youngstown Sheet and Tube Co., Dr. A. J. Unger, manager of the research bureau of the Carnegie Steel Co., and Homer D. Williams, president of the Pittsburgh Steel Co., have been invited by President Thomas S. Baker to become members of the advisory board of the Department of Metallurgical Engineering at Carnegie Institute of Technology, it is announced.

The advisory board, which is composed of about 25 steel company executives and metallurgists, is concerned primarily with the development of metallurgical research as now carried on jointly by the Carnegie Institute of Technology and the U. S. Bureau of Mines. Several important studies in ferrous metallurgy have been made under these auspices during

the past few years. T. D. Lynch, consulting metallurgical engineer to the Westinghouse Electric and Mfg. Co., is chairman of the board for the coming year.

Reconstruction of the American Engineering Standards Committee to keep pace with the growth of the industrial standardization movement in the United States is now under way, according to an announcement by the committee. The principal features of the reconstruction are the definite federation of national organizations, under the name American Standards Association, in such a way that trade associations interested in standardization may more readily join in the direction of the movement; placing the technical work of approving standards in a standards council; and concentrating administrative and financial responsibility in a board of directors composed of twelve industrial executives.

The reorganization has been unanimously approved by the main committee of the American Engineering Standards Committee, and is now being voted upon by the member bodies. The action of the committee results from more than a year's intensive consideration of the subject by the main committee and rules committee. The latter was enlarged for the purpose to include a representative of each of the 19 member-bodies desiring representation.

Strainers for use on systems for conveying fuel oil or other fluids are described in a folder issued by the Anthony Co., Long Island City, N. Y.
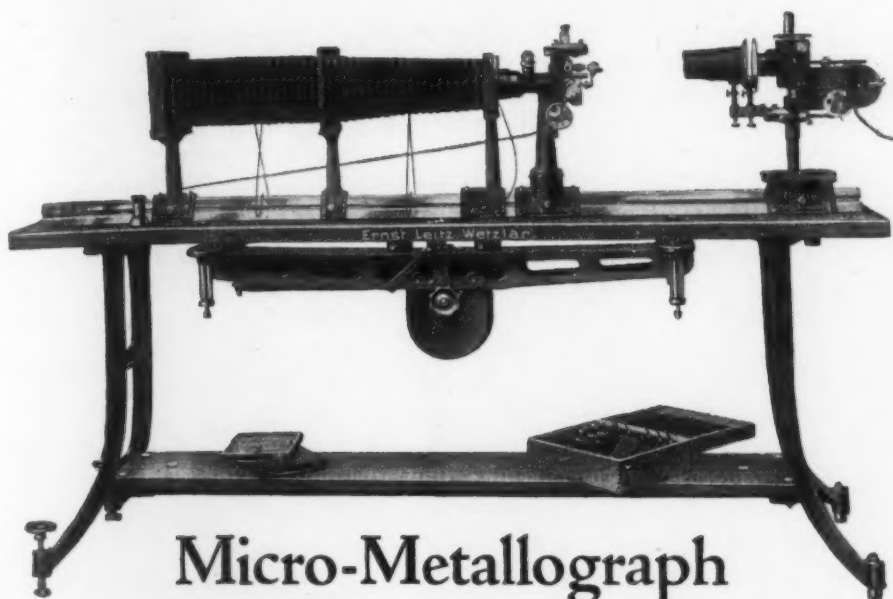

Electric box furnaces for the heat treating of dies, tools, and general heat treating operations are described in a bulletin issued by the James H. Herron Co., 1360 W. 3rd St., Cleveland.

The Bausch and Lomb Optical Co., Rochester, N. Y., has issued a catalog entitled, "Microscopes in Metallurgy." This may be obtained by addressing a request to the above company.

A 67-page illustrated booklet containing data on the embrittlement of boiler plate has been issued by the engineering experiment station, University of Illinois, Urbana, Ill. The results obtained from the tests are in part: neither the design nor the workmanship of the boilers investigated were responsible for the trouble; boiler plate material was found to be satisfactory; operation of the boilers was satisfactory except the nature of the feed water; embrittled boilers in all cases were accompanied by an alkaline condition of the boiler water with a low sulphate content; sodium hydroxide was the only material found in the boilers which had the effect of embrittling stressed steel; it was found that the embrittlement might be stopped or inhibited by increasing the sulphate content; new embrittlement inhibiting agents were developed.

The American Refractories Institute, 2202 Oliver Bldg., Pittsburgh, has issued bulletin 23. This covers the discussion held at the tunnel kiln symposium held in St. Louis in December, 1927.

There was relatively little change in the shipments of manganese ore containing 35 per cent of manganese or more in 1927, according to the United States Bureau of Mines, Department of Commerce. The shipments of this grade amounted to 44,741 long tons, valued at $1,151,918, in 1927, compared with 46,258 tons, valued at $1,228,663, in 1926. Shipments of metallurgical ore totalled 27,730 tons, valued at $446,781, and of chemical ore totalled 17,011 tons, valued at $705,137. This is an increase of 1200 tons in metallurgical ore and a decrease of 2700 tons in chemical ore shipments. The principal changes in shipments in the various states consisted of increases of 1200 tons in Arizona, 2400 tons in Idaho, 4400 tons in Montana and nearly 600 tons in Virginia, and decreases of nearly 2800 tons in Georgia, 1000 tons in Tennessee, and 3162 tons in Washington. A large part of the shipments from Montana was calcined rhodochrosite. The placing of this grade of material on the market indicates that the domestic production of manganese ore in 1928 will probably be materially increased. California, North Carolina and Washington, all of which shipped high-grade ore in 1926, made no shipments in 1927.

Shipments of ore containing 10 to 35 per cent of manganese were less than half as large as those in 1926, amounting to 148,291 tons, valued at $673,921, compared with 364,312 tons, valued at $1,179,429. The larger part of the decrease in shipments of this grade of ore is accounted for by the shipments in Michigan and Minnesota that were classed with ores containing over 10 per cent of manganese in 1926, and in 1927 fell below 10 per cent in manganese content. There were decreases, however, in total shipments of ore containing from 5 to 35 per cent of manganese in both of these states. Shipments of ore containing 10 to 35 per cent in Colorado increased from 2,925 tons in 1926 to 26,828 tons in 1927. New Mexico shipments increased over 4,500 tons.

Shipments of ore containing from 5 to 10 per cent of manganese amounted to 1,310,127 tons, valued at $3,270,460, in 1927, compared with 835,412 tons, valued at $1,934,381, in 1926, an increase in quantity of 474,-715 tons. This is entirely accounted for by Michigan and Minnesota ore that contained just over 10 per cent manganese, and Wisconsin ore that contained just under 5 per cent manganese in 1926, falling into the 5 to 10 per cent class in 1927.

The Columbia Tool Steel Company, Chicago Heights, Ill., states that it has secured and owns registered trade mark No. 230327, which covers the use of the word "SUPER" in conjunction with the word "DIE" on all tool steels, metals, metal castings, and forgings. This registered trade name is used in connection with their "Superdie High Carbon High Chromium Alloy."

Bulletin 30, "A Study of Spontaneous Combustion in Coal Storage," has been issued by the engineering experiment station of Purdue University, Lafayette, Ind. This bulletin is an effort to condense the published data on this subject so that producers, dealers and large consumers of coal may take advantage of the experiences of former coal storers and the findings of scientific research.

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